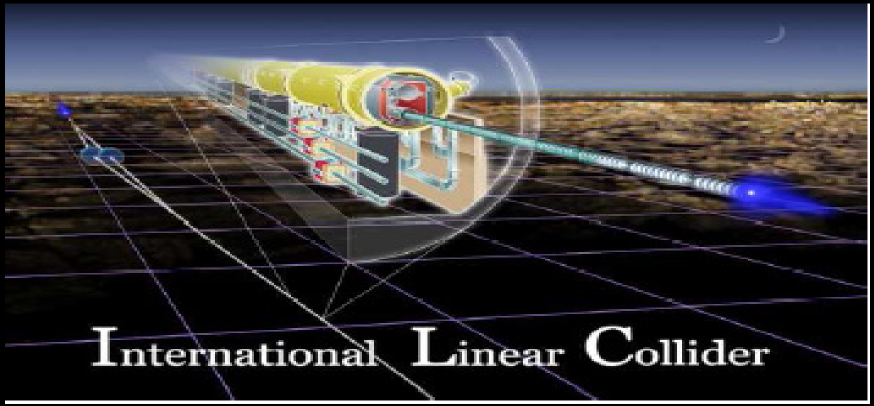
ILC MAIN LINAC SIMULATION



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OVERVIEW

- ILC Main Linac Simulation
  - ✓ Before Baseline Configuration Document (BCD)
    - ⇨ Status till Snowmass,'05

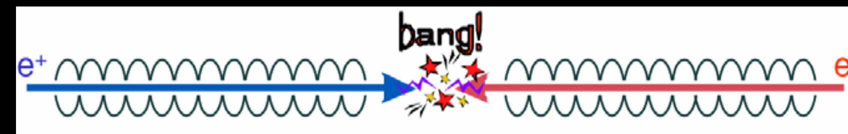
Performed similar work for NLC

- ➢ Study single-bunch emittance dilution in Main Linac
- ➢ Compare the emittance dilution performance of two different "beam-based steering" algorithms : "1:1" & "Dispersion Free Steering" under nominal conditions of static misalignments of the various beamline elements
- ➢ Compare the sensitivity of the steering algorithms for conditions different from the nominal
- ➢ Compare the different lattice configurations (with different Quad spacing)

  - ✓ After ILC BCD
    - ⇨ Preliminary results for the ILC BCD curved Linac
  - ✓ Benchmarking among various codes
- Summary / Plans

ILC MAIN LINAC

- ILC Main linac will accelerate e⁻/e⁺ beam from ~ 15 GeV → 250 GeV
  - ⇨ Upgradeable to 500 GeV



- Two major design issues:
  - ⇨ Energy : Efficient acceleration of the beams
  - ⇨ Luminosity : Emittance preservation

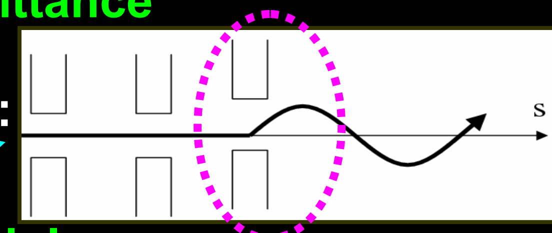
$$L \propto \frac{\eta_{RF} P_{RF}}{E_{cm}} \sqrt{\frac{\delta_{BS}}{\varepsilon_{n,y}}} H_D$$

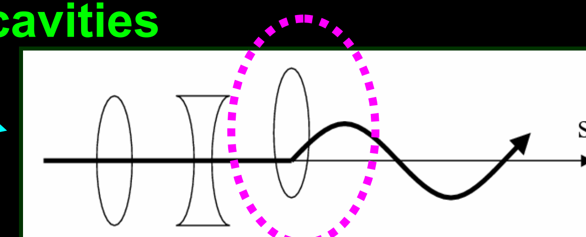
For High Luminosity

- high RF-beam conversion efficiency η_{RF}
- high RF power P_{RF}
- **small normalised vertical emittance $\varepsilon_{n,y}$**
- strong focusing at IP (small β_y and hence small σ_z)

- Vertical plane would be more challenging:
  - ⇨ Large aspect ratio (x:y) in both spot size and emittance

- Primary sources of emittance dilution (single bunch):
  - ⇨ Transverse Wakefields:
    - Short Range : misaligned cavities or cryomodules
  - ⇨ Dispersion from Misaligned Quads or Pitched cavities
  - ⇨ XY-coupling from rotated Quads
  - ⇨ Transverse Jitter





Before Baseline Configuration Document (BCD)
Status till Snowmass,'05

(Acknowledgement to Peter Tenenbaum (SLAC))

SIMULATION: MATLAB + LIAR (MATLIAR)

- LIAR (LInear Accelerator Research Code)
  - ⇨ General tool to study beam dynamics
  - ⇨ Simulate regions with accelerator structures
  - ⇨ Includes wakefield, dispersive and chromatic emittance dilution
  - ⇨ Includes diagnostic and correction devices, including BPMs, RF pickups, dipole correctors, magnet movers, beam-based feedbacks etc

- MATLAB drives the whole package allowing fast development of correction and feedback algorithms

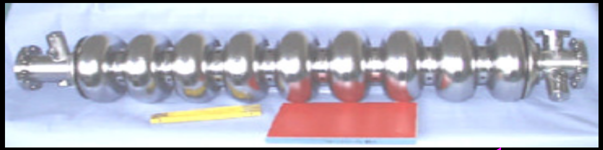
- CPU Intensive: Dedicated Processors for the purpose

USColdLC MAIN LINAC

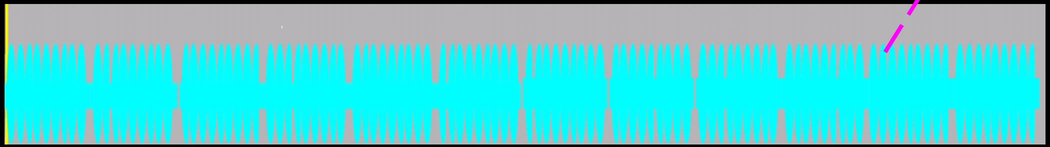
- USColdLC Main Linac Design
  - Linac Cryogenic system is divided into Cryomodules(CM), with **12 RF cavities / CM**
  - **1 Quad / 2CM** : Superconducting Quads in alternate CM, **330 Quads** (165F,165D)
  - Magnet Optics : FODO "constant beta" lattice, with β phase advance of **60^0** in each plane
  - Each quad has a *Cavity style BPM* and a *Vertical Corrector* magnet; horizontally focusing quads also have a nearby *Horizontal Corrector* magnet.

- Main Linac Parameters
  - ~**11.0 km** length
  - **9 Cell** cavities at **1.3 GHz**; Total cavities : **7920**
  - Loaded Gradient : **30 MV/m**
  - Injection energy = **5.0 GeV** & Initial Energy spread = **2.5 %**
  - Extracted beam energy = **250 GeV** (500 GeV CM)

- Beam Conditions
  - Bunch Charge: **2.0×10^{10} particles/bunch**
  - Bunch length = **300 μm**
  - Normalized injection emittance:
    - **$\gamma\varepsilon_Y$ = 20 nm-rad**



TESLA SC 9-Cell Cavity



12 "9-Cell Cavity" CryoModule

USColdLC MAIN LINAC

ab initio (Nominal) installation conditions

Tolerance	Vertical (y) plane
BPM Offset w.r.t. Cryostat	300 μm
Quad offset w.r.t. Cryostat	300 μm
Quad Rotation w.r.t. Cryostat	300 μrad
Cavity Offset w.r.t. Cryostat	300 μm
Cryostat Offset w.r.t. Survey Line	200 μm
Cavity Pitch w.r.t. Cryostat	300 μrad
Cryostat Pitch w.r.t. Survey Line	20 μrad
BPM Resolution	1.0 μm

- BPM transverse position is fixed, and the BPM offset is w.r.t. Cryostat

  Only Single bunch used

  No Ground Motion and Feedback

  Steering is performed using Dipole Correctors

10 nm (50%) Vertical emittance growth in main linac

Normalized Emittance Dilution Budget

		DR Exit	=>	ML Injection	=> ML Exit	=> IP
USColdLC:	Hor./Vert (nm-rad):	8000 / 20	=>	8800 / 24	=> 9200 / 34	=> 9600 / 40

ALIGNMENT & STEERING ALGORITHMS

- Beam line elements are needed to be aligned with beam-based measurements
- "Beam Based Alignments (BBA)" refer to the techniques which provide information on beamline elements using measurements with the beam
  - Quad strength variation ← Estimate beam-to-quad offset
  - **"One-to-One" Correction**
  - **Dispersion Free Steering**

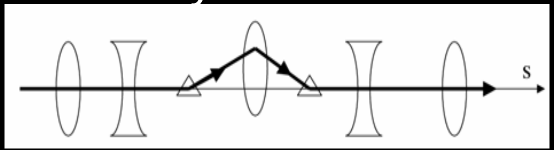
    Considered here
  - Ballistic Alignment
  - Kick minimization method *and possibly others*….

- ***Quad Shunting:*** Measure beam kick vs. quad strength to determine BPM-to-Quad offset (routinely done)

- In USColdLC, it was not assumed that all quads would be shunted
  - **Quads are Superconducting and shunting might take a very long time**
  - **No experimental basis for estimating the stability of the Magnetic center as a function of excitation current in SC magnets**
  - **In Launch region (1st 7 Quads), we assume that offsets would be measured and corrected with greater accuracy (~30 μm)**

Beam based alignment - 1:1 Steering

- Beam is steered to zero the transverse displacements measured by the BPMs. The BPMs are typically mounted inside the quadrupoles.



- Quad alignment – How to do?
  - ☞ **Find a set of corrector readings for which beam should pass through the exact center of every quad (zero the BPMs)**
  - ☞ **Use the correctors to steer the beam**

corrector kick

Beam position at downstream BPM

$$x_j = \sum_{i=1}^{j-1} \sqrt{\frac{E_i}{E_j}} \sqrt{\beta_i \beta_j} \theta_i \sin(\phi_j - \phi_i)$$

MATRIX form

$$\boldsymbol{x} = M \boldsymbol{\theta}$$

$$\begin{aligned} x^T &= (x_0, x_1, ..., x_m) \\ \theta^T &= (\theta_0, \theta_1, ..., \theta_n) \\ M_{ij} &= \sqrt{\beta_i \beta_j} \sin(\phi_j - \phi_i) \end{aligned}$$

m is the total number of BPM measurements

n is the total number correctors

Solving the matrix equation:

$$M^T \boldsymbol{x} = M^T M \boldsymbol{\theta}$$

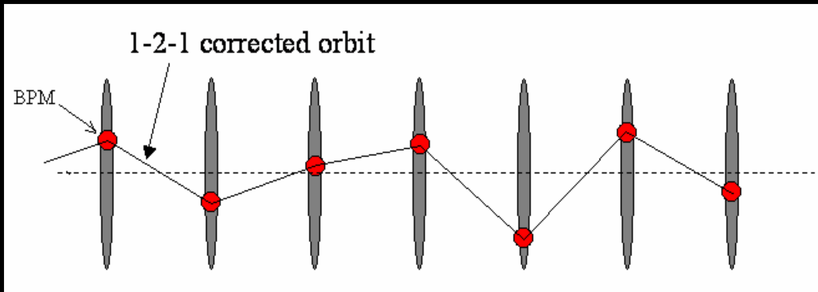
Θ is the vector containing the unknown kick angles

$$\boldsymbol{\theta} = (M^T M)^{-1} M^T \boldsymbol{x}$$

x is the vector containing the BPM measurements

For equal no. of YCOR and BPM

$$\vec{\theta} = M^{-1} \vec{x}.$$



- **One-to-One alignment generates *dispersion* which contributes to emittance dilution and is sensitive to the BPM-to-Quad offsets**

Beam based alignment – Dispersion Free Steering

- DFS is a technique that aims to directly measure and correct dispersion in a beamline **(proposed by Raubenheimer / Ruth, NIMA302, 191-208, 1991)**
- General principle:
  - **Measure dispersion (via mismatching the beam energy to the lattice)**
  - **Calculate correction needed to zero dispersion**
  - **Apply the correction**

minimize the absolute orbit and the difference orbit simultaneously:

$$\sum_j \left[x_j - \sum_i M_{ji}\theta_i \right]^2$$

$$\begin{bmatrix} x_1 \\ x_2 \\ . \\ . \\ . \\ x_M \\ \Delta x_1 \\ \Delta x_1 \\ . \\ . \\ . \\ \Delta x_M \end{bmatrix} \quad \begin{bmatrix} R_{12}{}^{11} & \dots & R_{12}{}^{1N} \\ . & \dots & . \\ . & \dots & . \\ . & \dots & . \\ R_{12}{}^{11,\kappa} & \dots & R_{12,\kappa}{}^{1N} \\ . & \dots & . \\ . & \dots & . \\ . & \dots & . \end{bmatrix} \quad \begin{bmatrix} \theta_1 \\ \theta_2 \\ . \\ . \\ . \\ \theta_N \end{bmatrix}$$

(2M×1) **(2M×N)** **(N×1)**

Constraint:

$$\sum_j \left[\frac{x_j{}^2}{\sigma_{\rm bpm}{}^2} + \frac{\Delta x_j{}^2}{\sigma_{\rm sys}{}^2} \right]$$

Absolute orbit:

$$x_j = \sum_{i=1}^{j-1} \sqrt{\frac{E_i}{E_j}} \sqrt{\beta_i \beta_j}\, \theta_i \sin(\phi_j - \phi_i) = \sum_{i=1}^{j-1} R_{12}^{ij} \theta_i$$

Difference orbit:

$$\Delta x_j = \sum_{i=1}^{j-1} R_{12,\kappa}^{ij} \theta_i$$

- **Successful in rings (LEP, PEP) but less successful at SLC (Two-beam DFS achieved better results)** ***(Note: SLC varied magnet strengths (center motion?), others varied beam energy)***

STEERING ALGORITHM : ONE-to-ONE vs. DFS

1:1

Divide linac into segments of ~50 quads in each segment:

- Read all Q-BPMs in a single pulse
- Compute set of corrector readings and apply the correction
  - Constraint – minimize RMS of the BPM readings
- Iterate few times before going to the next segment.
- Performed for 100 Seeds

DFS

Divide linac into segments of ~40quads

- Two orbits are measured
- Vary energy by switching off cavities in front of a segment (no variation within segment)
- Measure change in orbit (fit out incoming orbit change from RF switch-off)
- Apply correction
  - Constraint – simultaneously minimize dispersion and RMS of the BPM readings (weight ratio: $\sqrt{2} : 300$)
- Iterate twice before going to the next segment
- Performed for 100 Seeds

- Launch Region (1st seven BPMs) Steering (can not be aligned using DFS)
  - ⇨ Emittance growth is very sensitive to the element alignment in this region, due to low beam energy and large energy spread
  - ⇨ First, all RF cavities in the launch region are switched OFF to eliminate RF kicks from pitched cavities / cryostats
  - ⇨ Beam is then transported through the Launch and BPM readings are extracted => estimation of Quad offsets w.r.t. survey Line
  - ⇨ Corrector settings are then computed which ideally would result in a straight trajectory of the beam through the launch region
  - ⇨ The orbit after steering the corrector magnets constitutes a reference or "gold" orbit for the launch
  - ⇨ The RF units are then restored and the orbit is re-steered to the Gold Orbit. (This cancels the effect of RF kicks in the launch region)

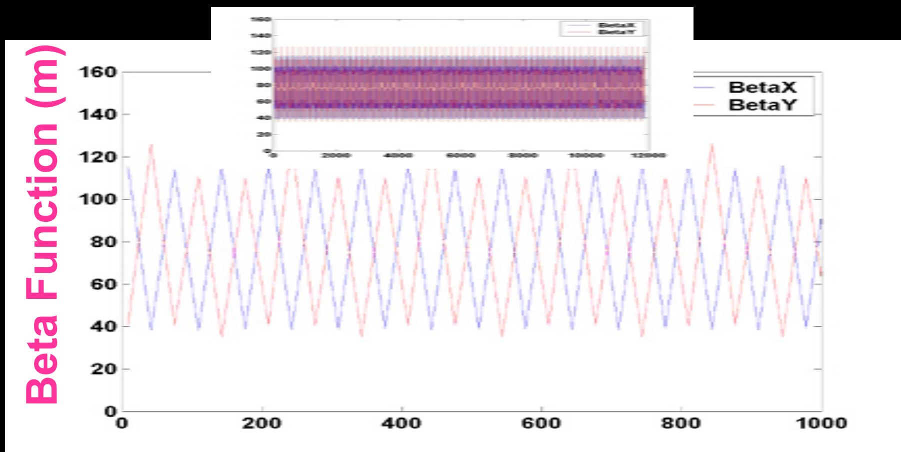
STEERING ALGORITHM : ONE-to-ONE vs. DFS

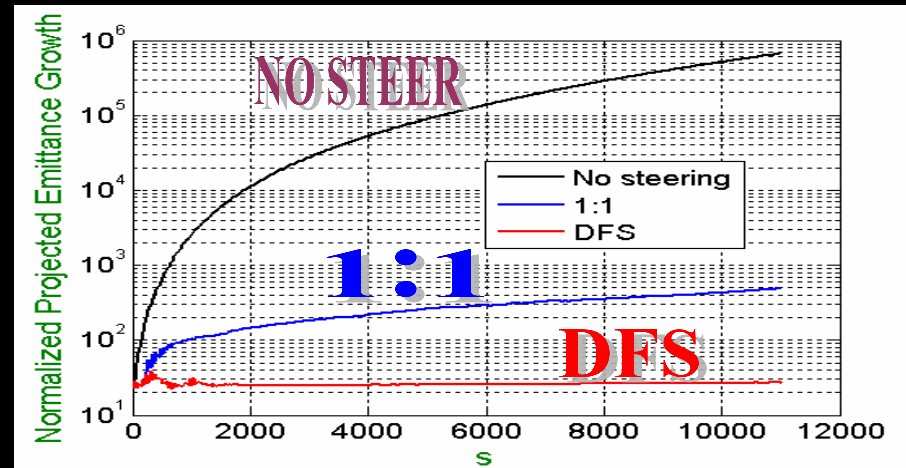
Flat Steering	
Number of steering regions:	7
Overlap in steering regions:	0.1
Number iterations steering per region:	3
Number "front-end" BPMs:	7
(used for launch region)	

DFS	
Number of DFS regions:	18
Overlap in DFS regions:	0.5
Number iterations DFS per region:	2
DFS Max relative energy change:	0.2
DFS Max absolute energy change [GeV]:	18
DFS Endpoint for Region 1 Energy Change (Q#):	4

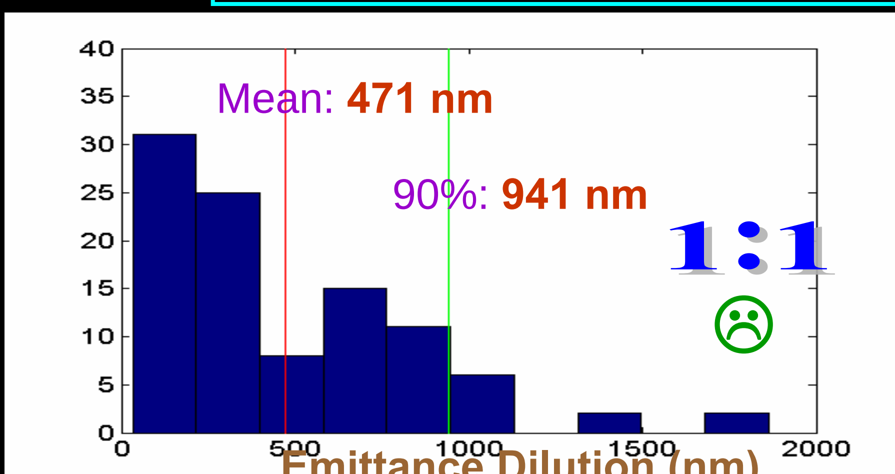
FOR USColdLC NOMINAL CONDITIONS

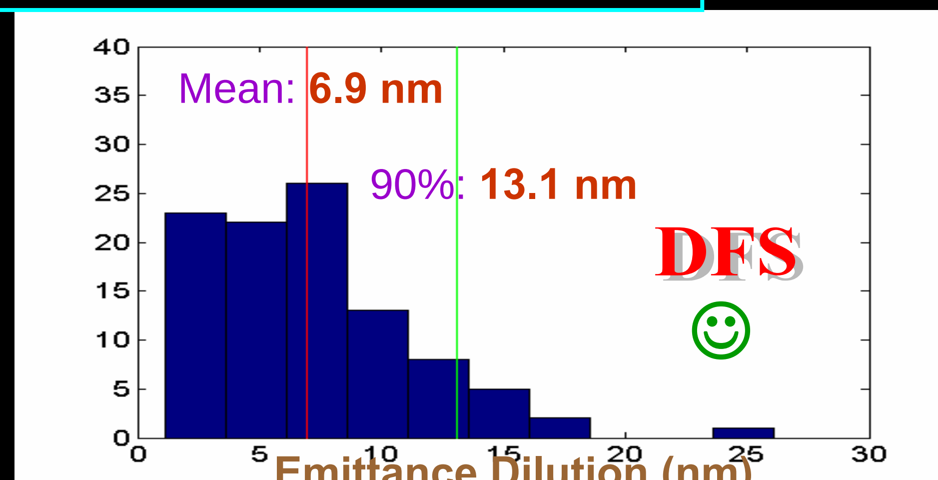
- Gradient : 30 MV/ m; 100 seeds





Projected Emittance Dilution = Emittance (Exit) – Emittance (Entrance)

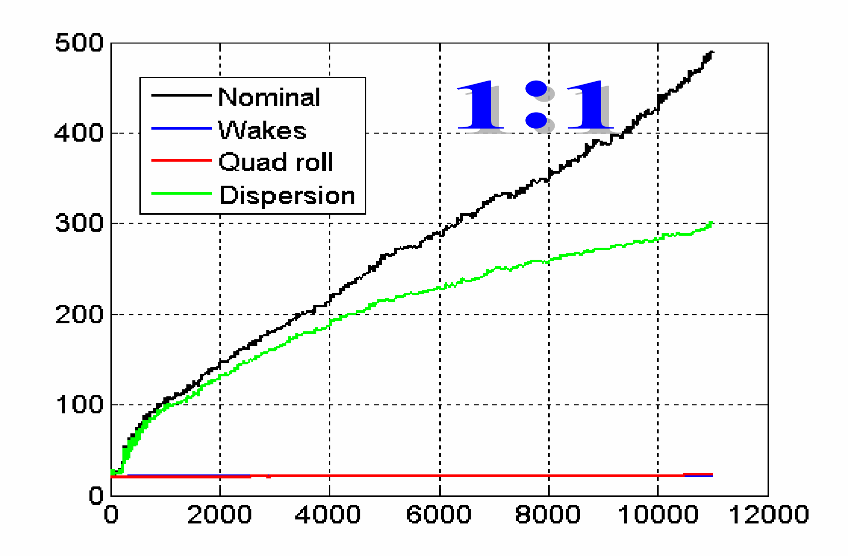


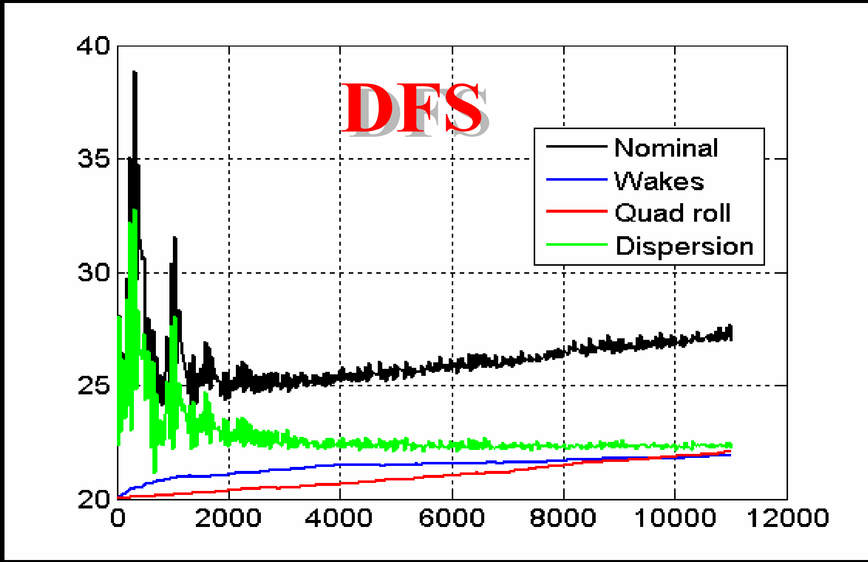


- ☞ Lower mean emittance growth for DFS than One-to-One
- ☺ Mean Growth under the Emittance dilution budget ← No Jitter and No BNS energy spread!

FOR USColdLC NOMINAL CONDITIONS

Average Normalized Emittance Growth (nm) vs. s (m)





Average Normalized Emittance Dilution (nm)

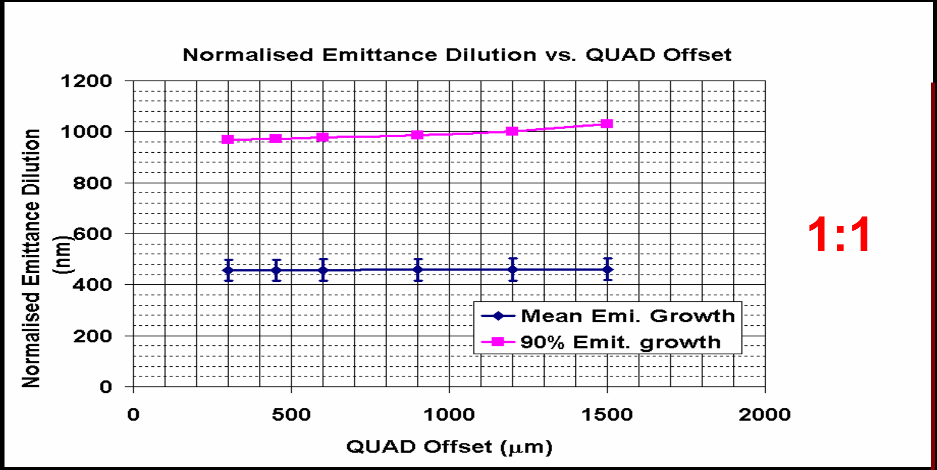
Tolerance	1:1	DFS
Nominal	470	6.9
Wakes only	1.9	1.9
Dispersion only	280	2.2
Quad roll only	2.1	2.1

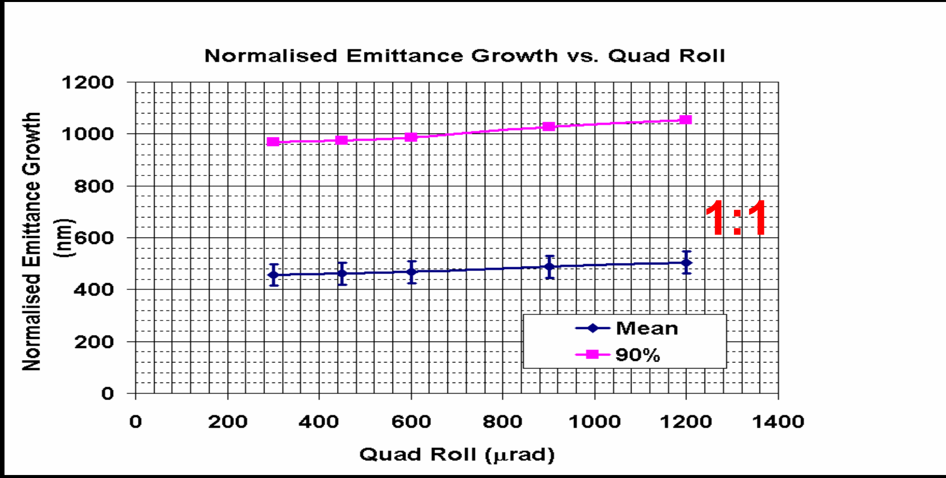
Almost equal contributions

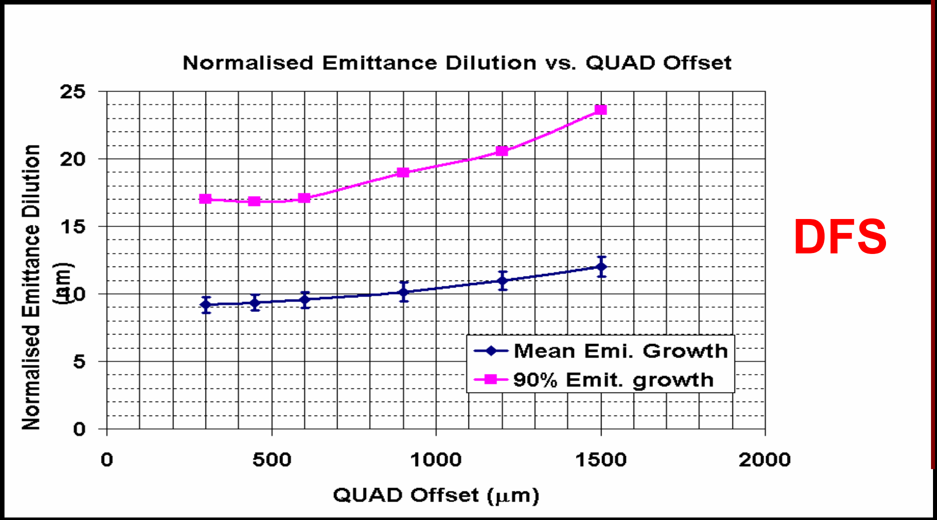
- Wakes include only Cavity and CM offsets; Dispersion includes Quad / BPM Offsets & Cavity / CM pitches
- Nominal >Wakes+Dispersion+Quad roll (Why?– wakefields causing systematic errors ?)

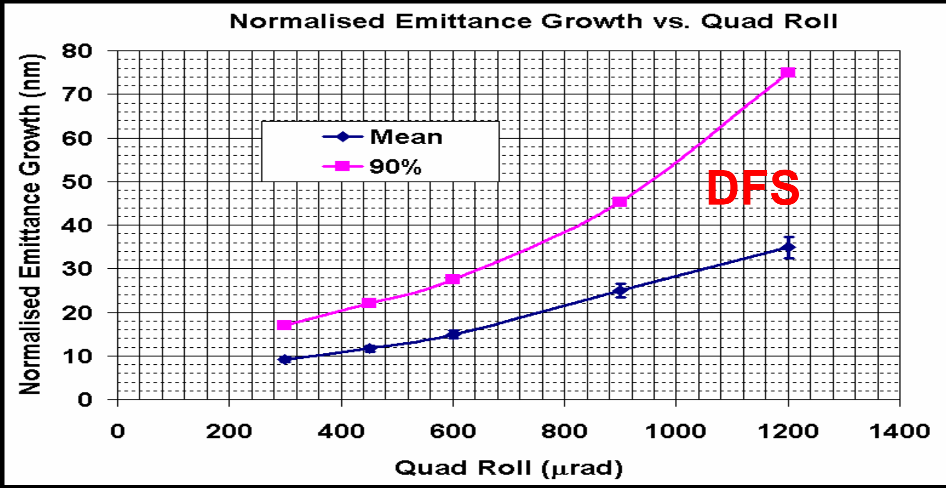
EFFECT OF *QUAD OFFSETS / QUAD ROLLS* VARIATION

➤ Keeping all other misalignments at Nominal Values and varied only the Quad offsets



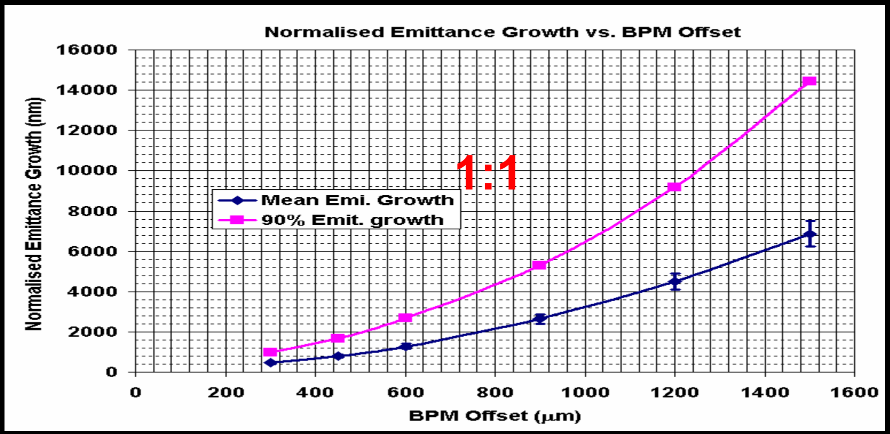


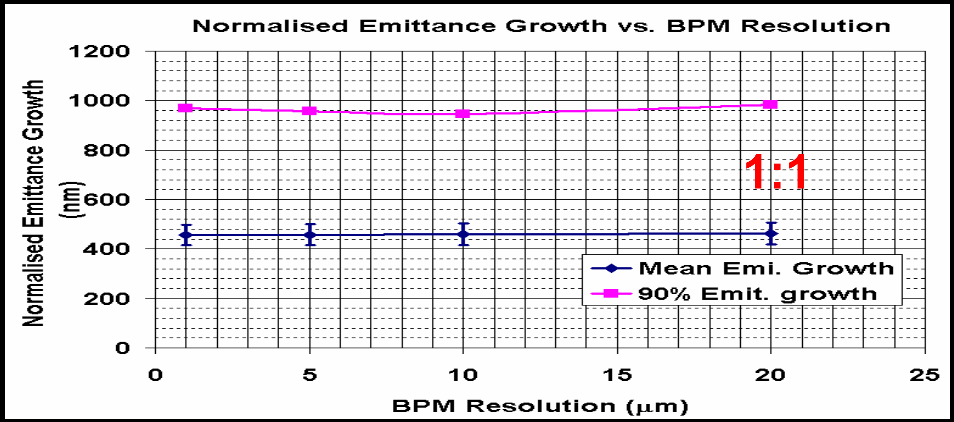


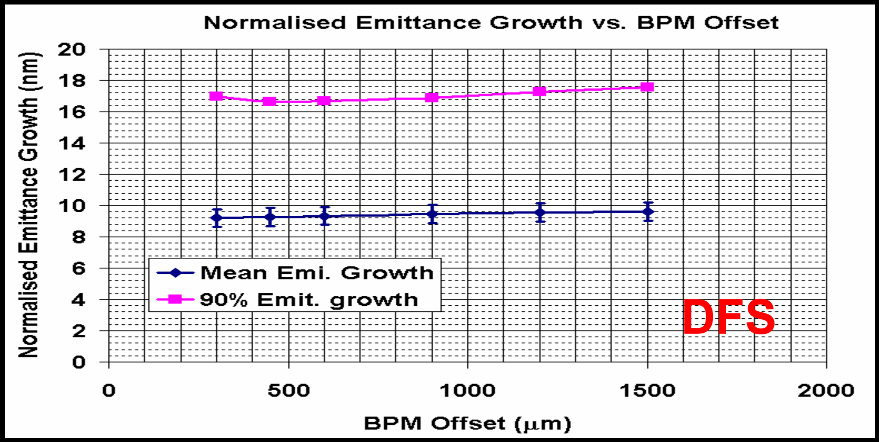


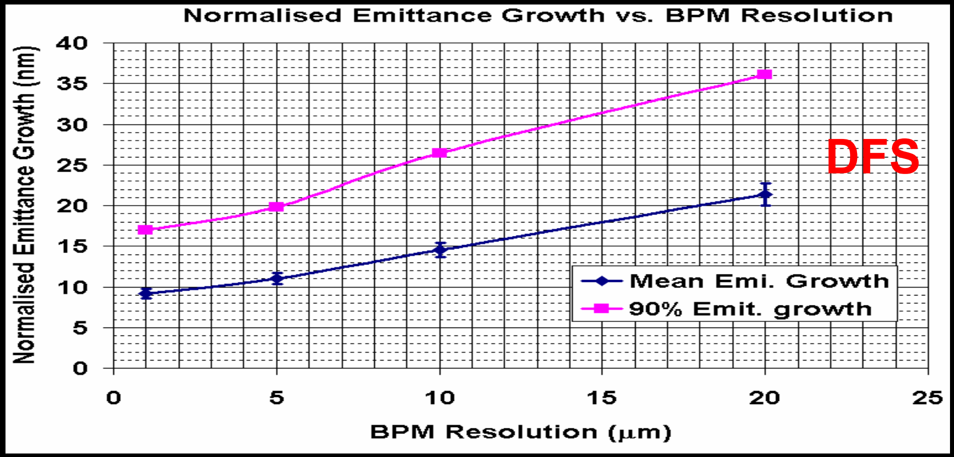
- Emittance dilution increases slowly with increase in Quad Offsets
- DFS: Just under the budget for 2x nominal values
- DFS: Emittance dilution increases more rapidly with increase in Quad Roll
- DFS: Goes Over the budget even for 1.5x nominal values

EFFECT OF *BPM OFFSETS / RESOLUTION* VARIATION



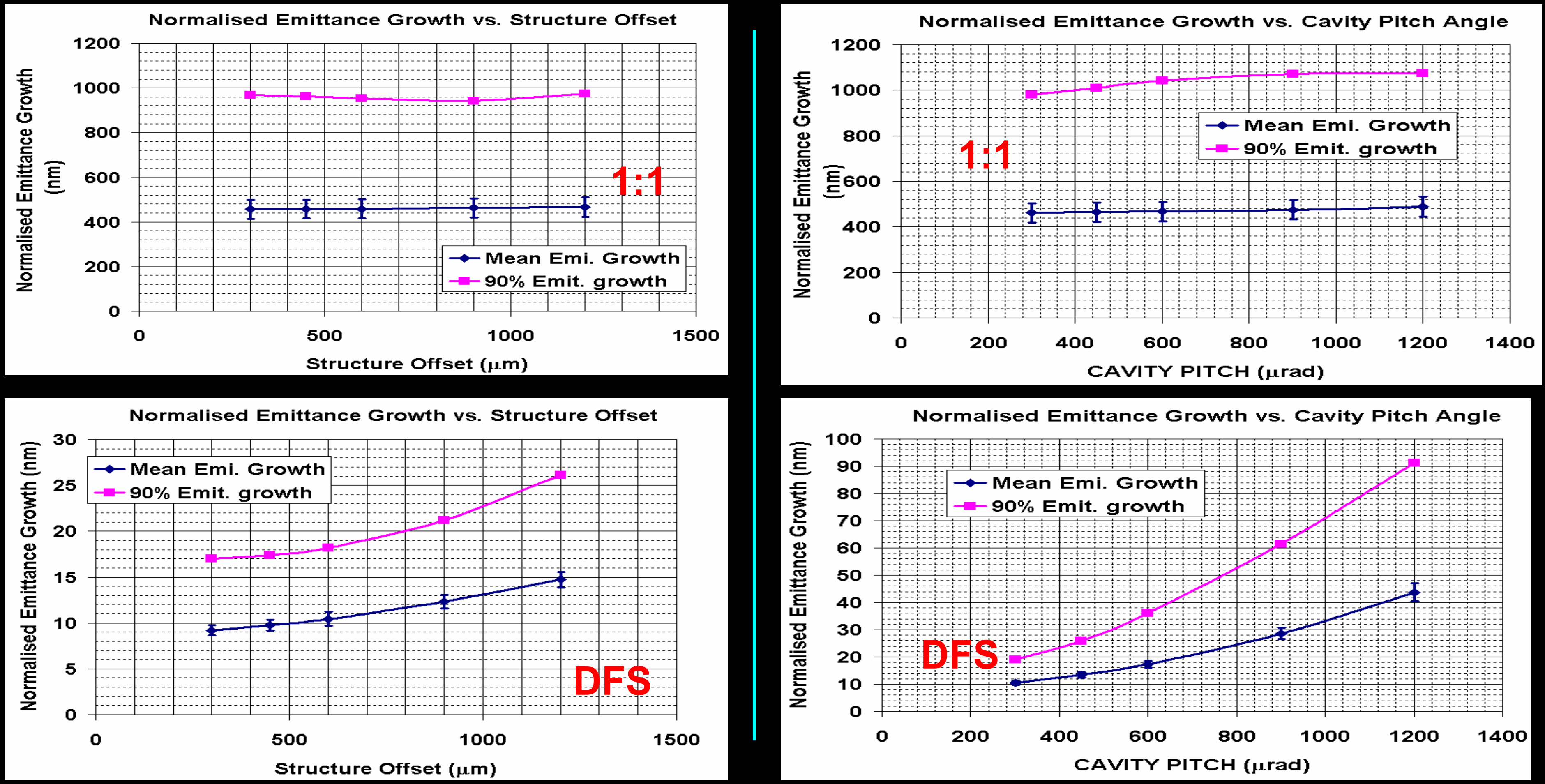






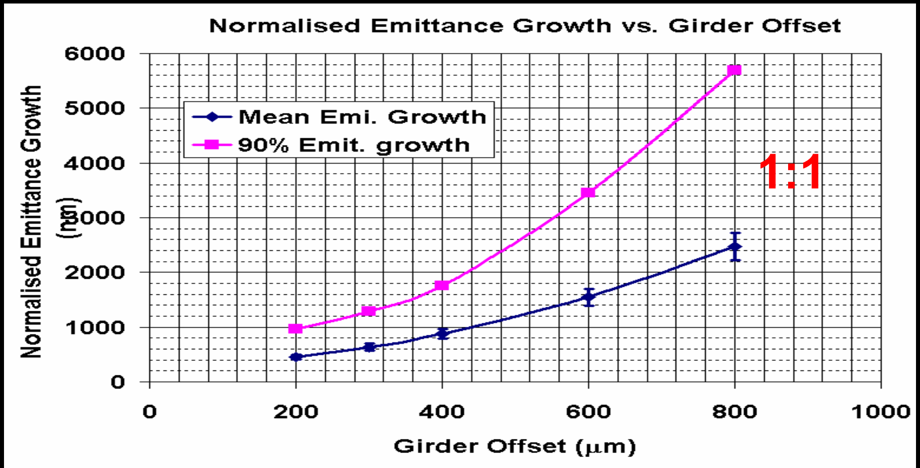
- *Advantage of DFS:* Emittance dilution for 1:1 increases very sharply with BPM offsets
- DFS: Emittance dilution is almost independent of BPM offset
- DFS: Remains within the budget even for 5x nominal
- Emittance dilution for 1:1 is almost independent of the BPM resolution
- DFS: Emittance dilution is sensitive to BPM resolution
- DFS: Goes Over the budget even for 5x nominal values

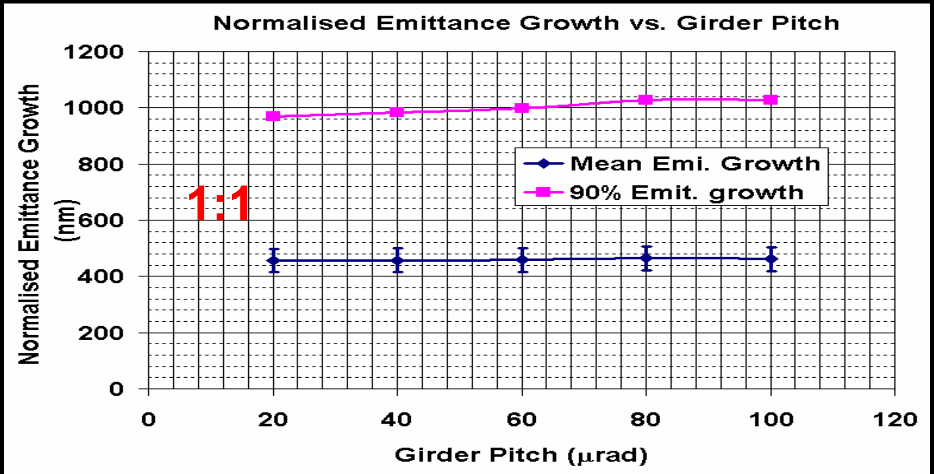
EFFECT OF *STRUCTURE OFFSET / PITCH* VARIATION

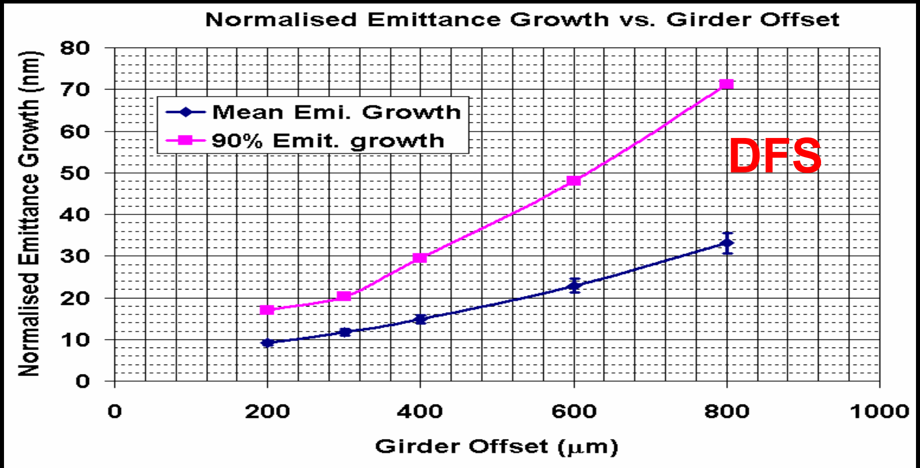


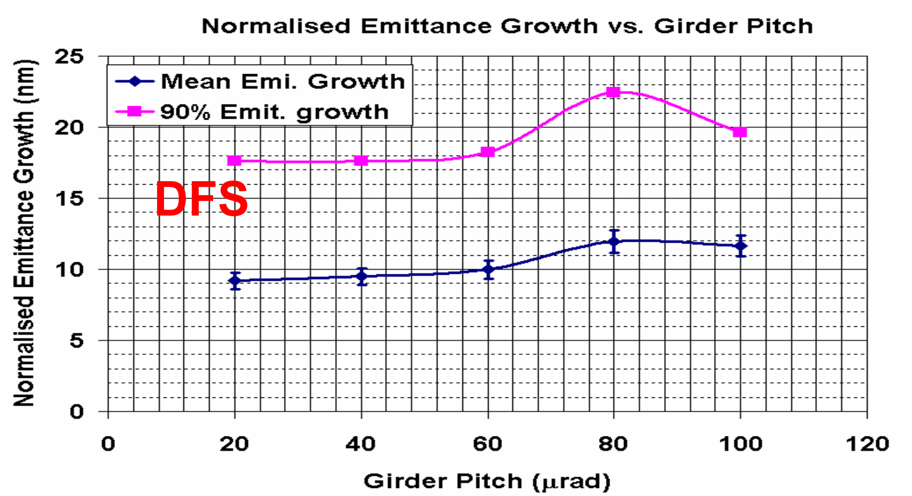
- **Emittance dilution for 1:1 is almost independent of the structure offset**
- **DFS: Emittance dilution grows slowly with structure offsets**
- **DFS: Goes Over the budget for 2.0x nominal values**
- DFS: Emittance dilution is sensitive to Cavity pitch
- DFS: Goes Over the budget even for 1.5x nominal values

EFFECT OF *CRYOMODULE OFFSET/ PITCH* VARIATION





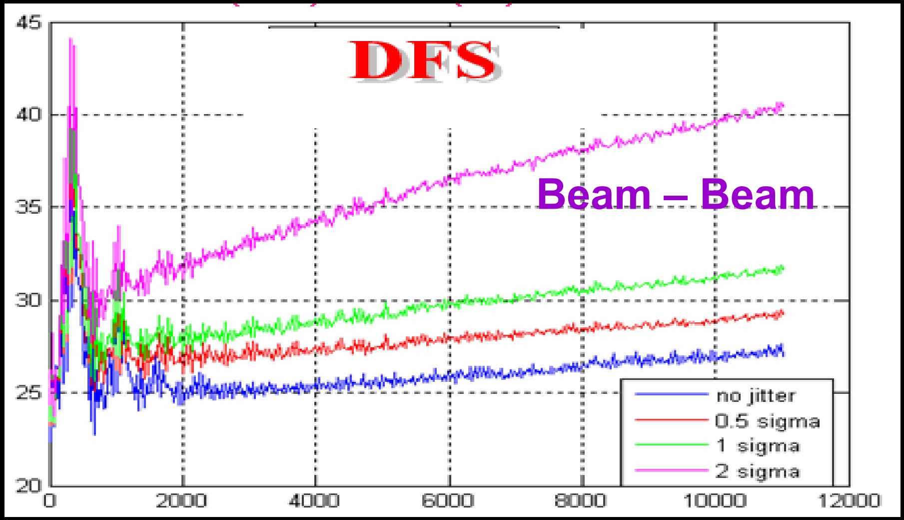


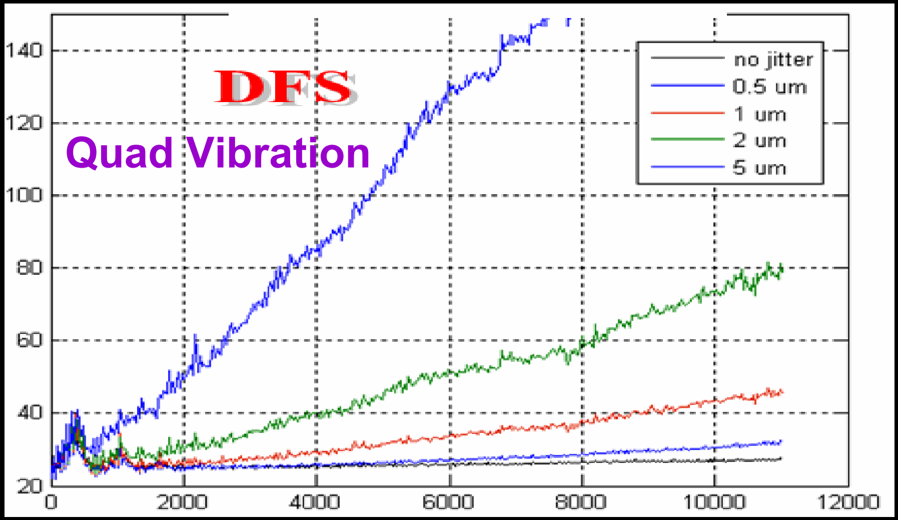


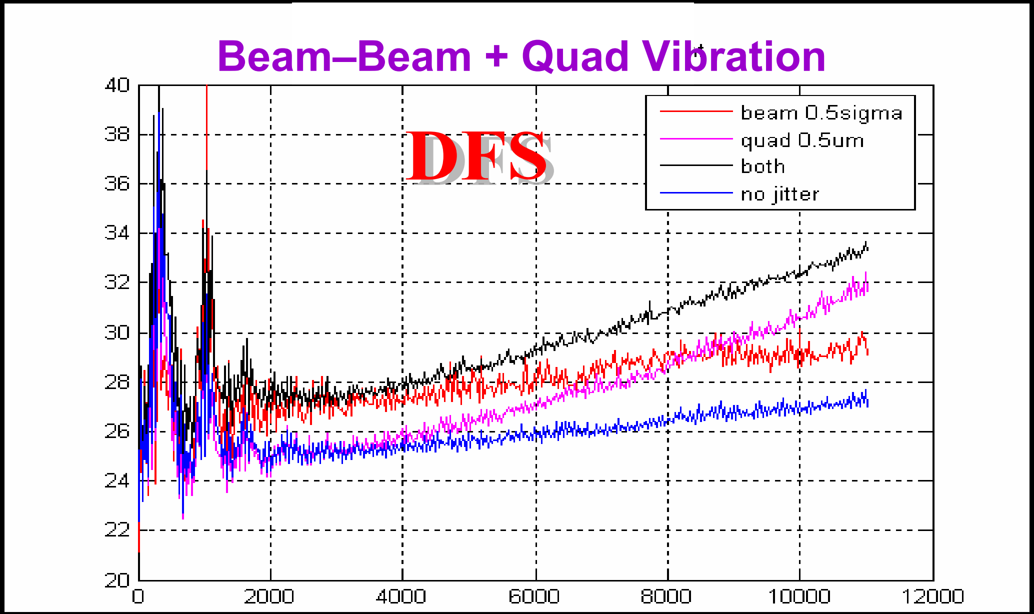
- DFS and 1:1: Emittance dilution grows sharply with CM offset
- DFS: Goes Over the budget even for 1.5x nominal values
- DFS and 1:1: Emittance dilution is almost independent of the CM pitch
- DFS: Remains within the budget for 3x nominal

Effect of Including JITTER

Average Normalized Emittance Growth (nm) vs. s (m)





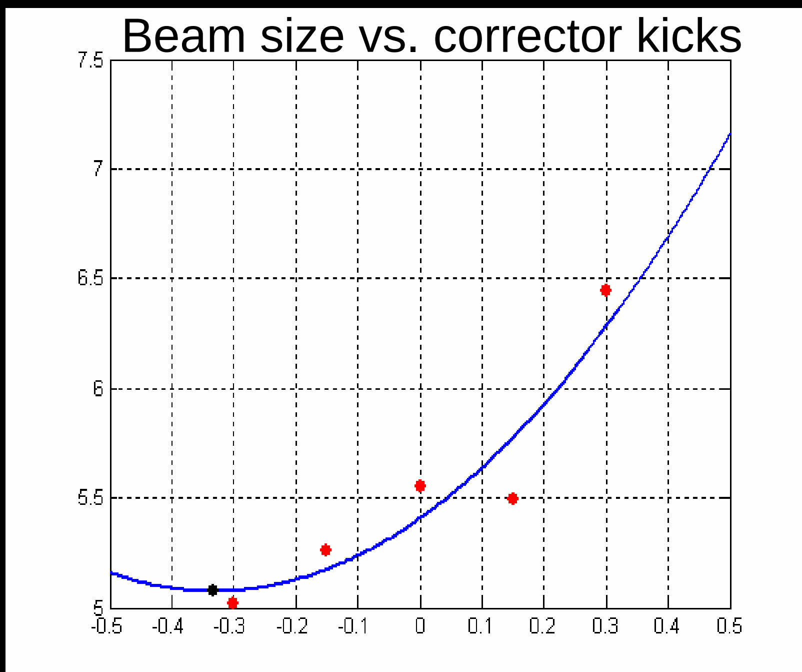


Dispersion Bumps

It changes y-position for structure or field for y-corrector

Reads information about vertical beam size from wire monitor at the end of linac for a few times

Two y-correctors located 180^0 apart in phase such that 1st one generates dispersion and the other one cancels it



Makes approximation of data using parabola:

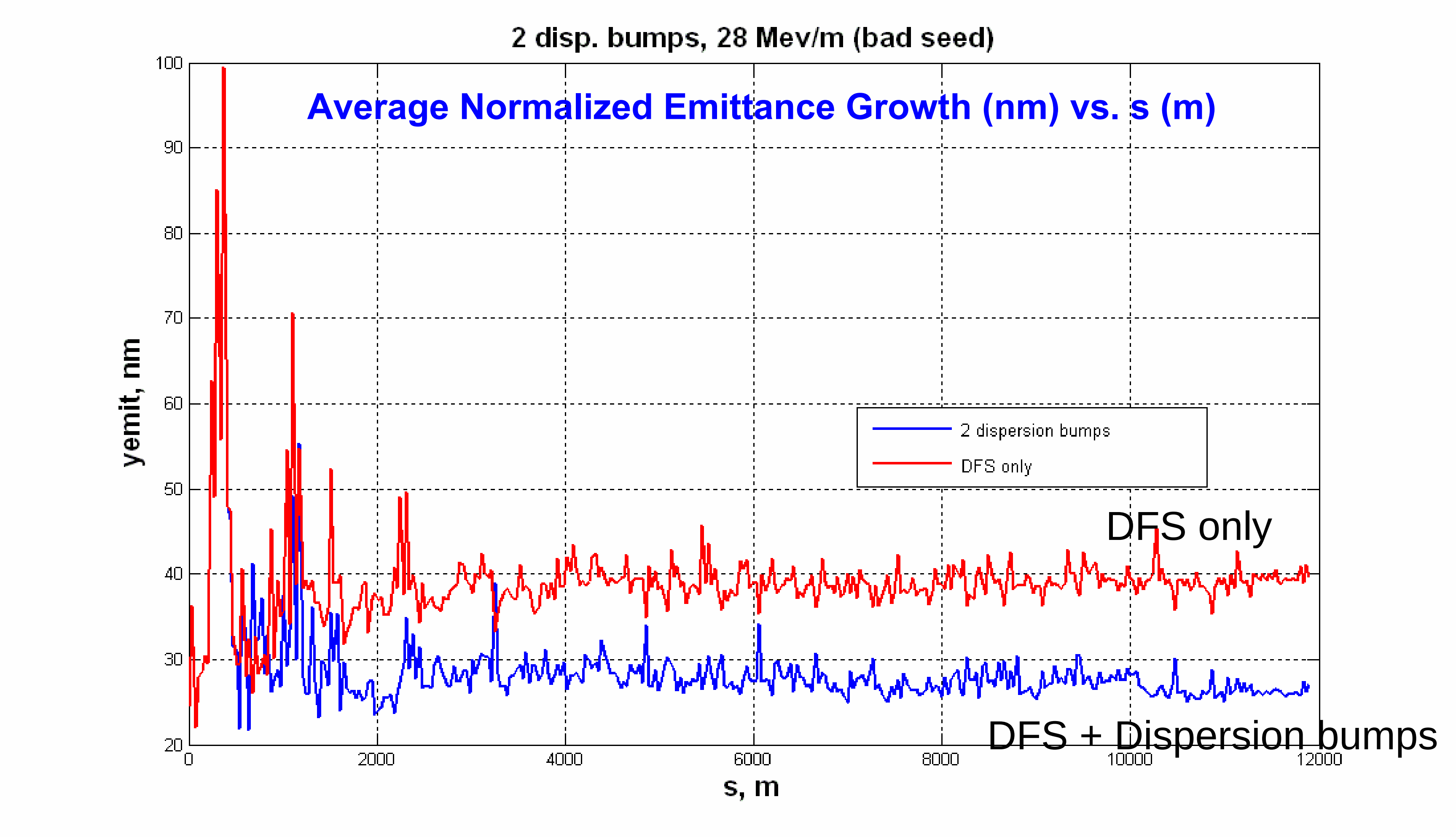
$y=A\,(x - B)^2 + C$

Takes a minimal value of vertical beam size which corresponds to minimum of parabola

Contributed by :N.Solyak + E. Shtarklev

Dispersion Bumps

Two dispersion bumps applied for bad seed

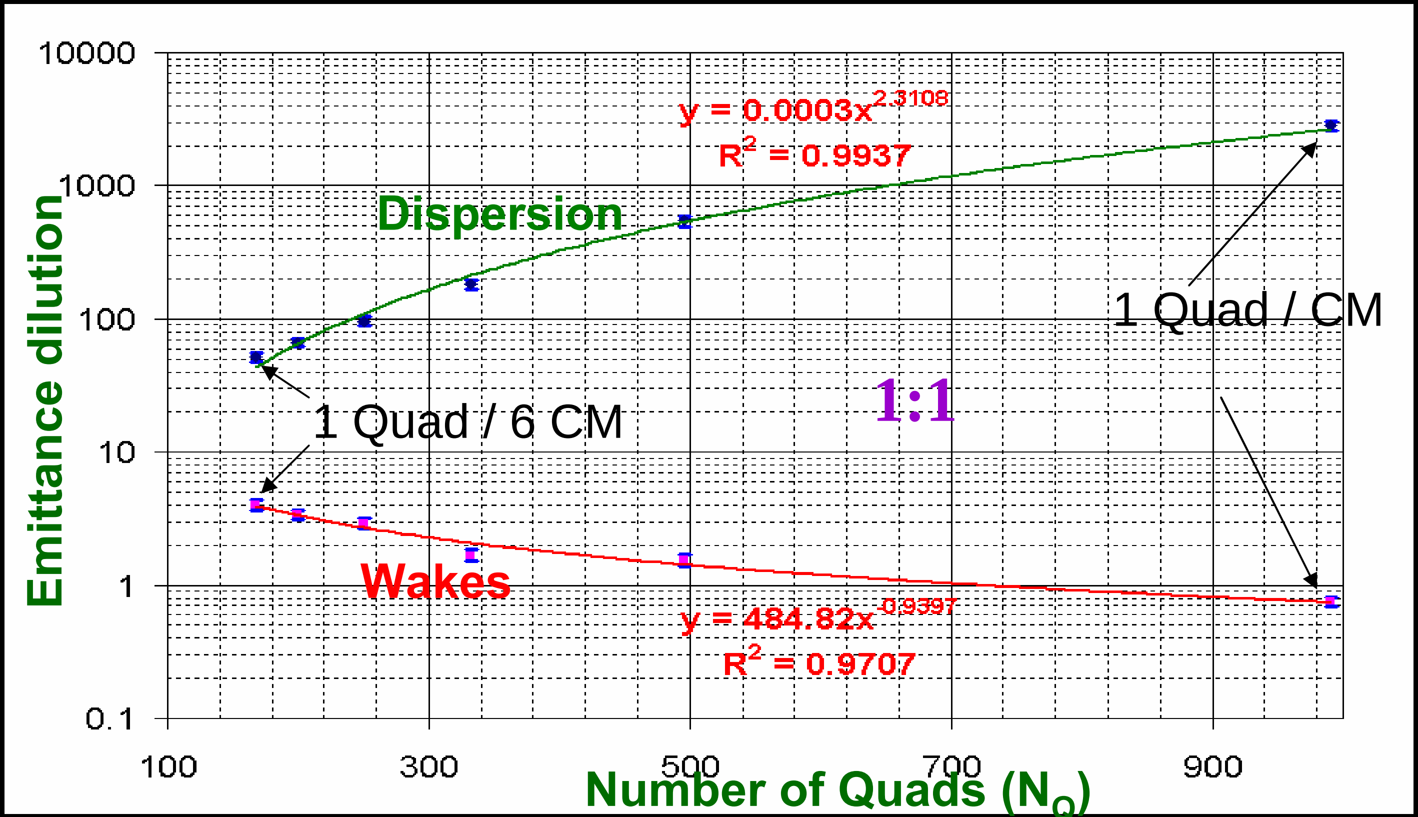


➢ Inclusion of bumps can help in further minimizing the emittance dilution after steering, also important for bad seeds

Contributed by :N.Solyak + E. Shtarklev

QUAD CONFIGURATION

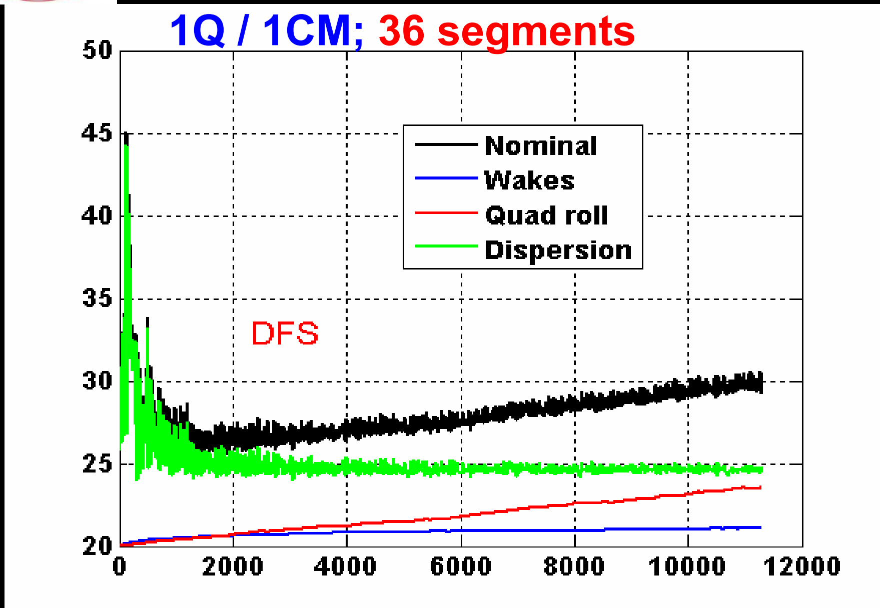
- 8 configurations with diff. quad spacing (from 1 Quad / 1CM to 1 Quad / 8CM)
- Dispersion Case – Quad, BPM Offsets and Structure, CM Pitch
- Wake Case – Structure, CM offset, wakefields

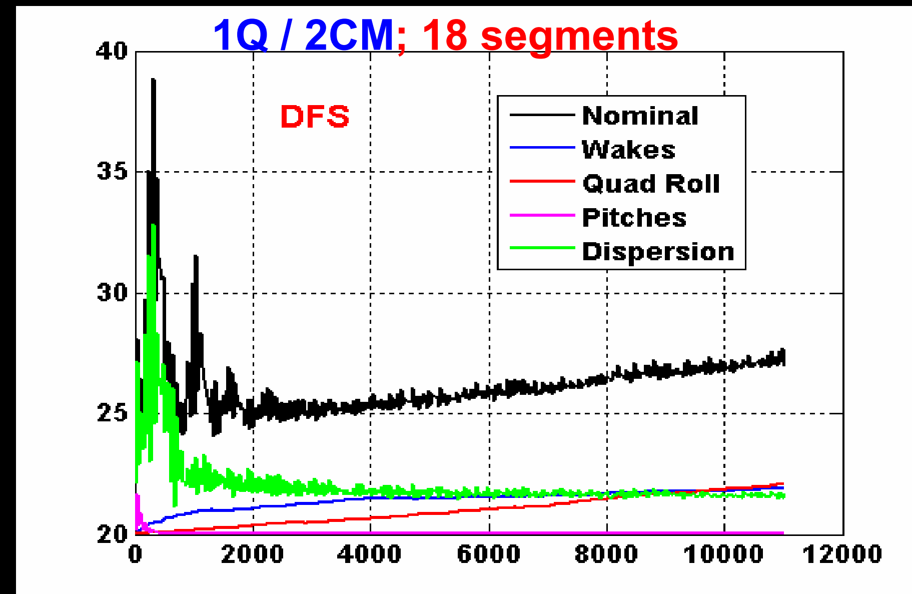


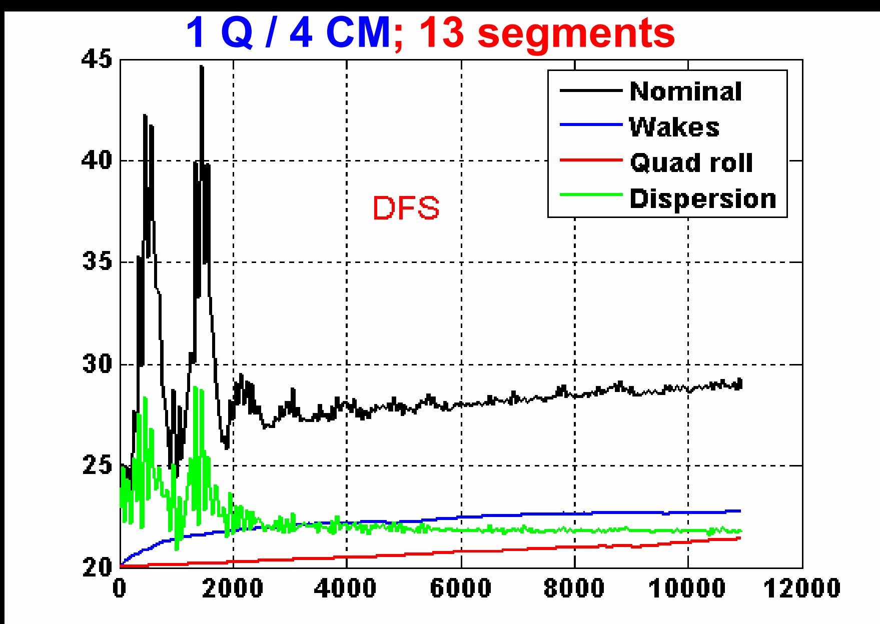
30 MV/m
TTF CM
8 Cavity / CM

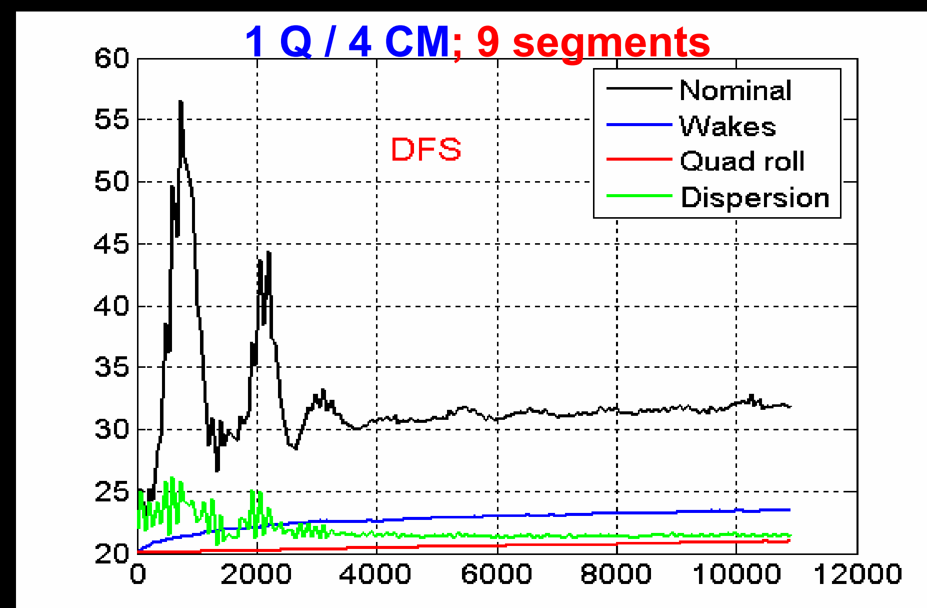
☞ Projected emittance growth is dominated by dispersive sources
☞ Large quad spacing seems to be an attractive choice (?)

EMITTANCE DILUTION – SOURCES

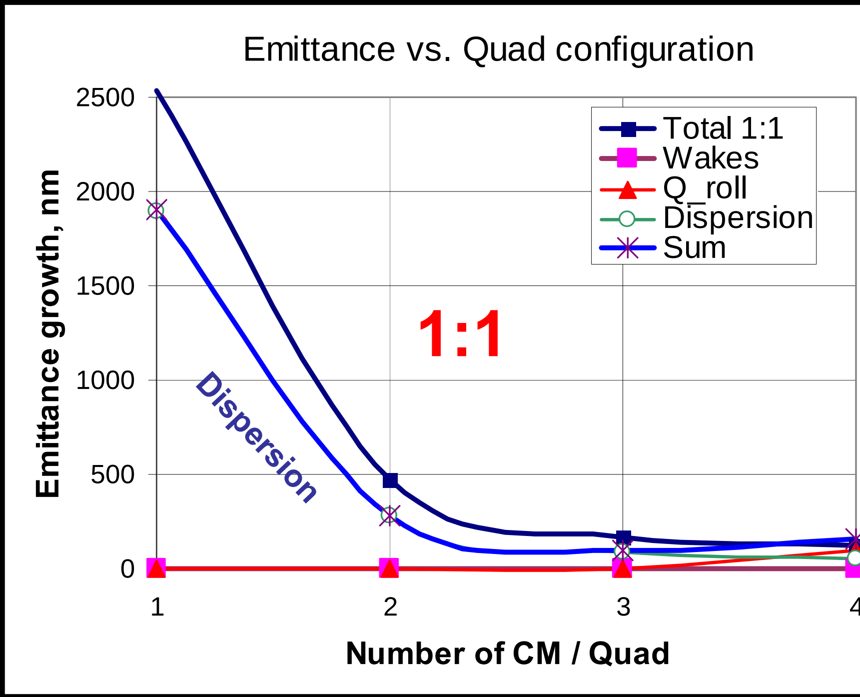


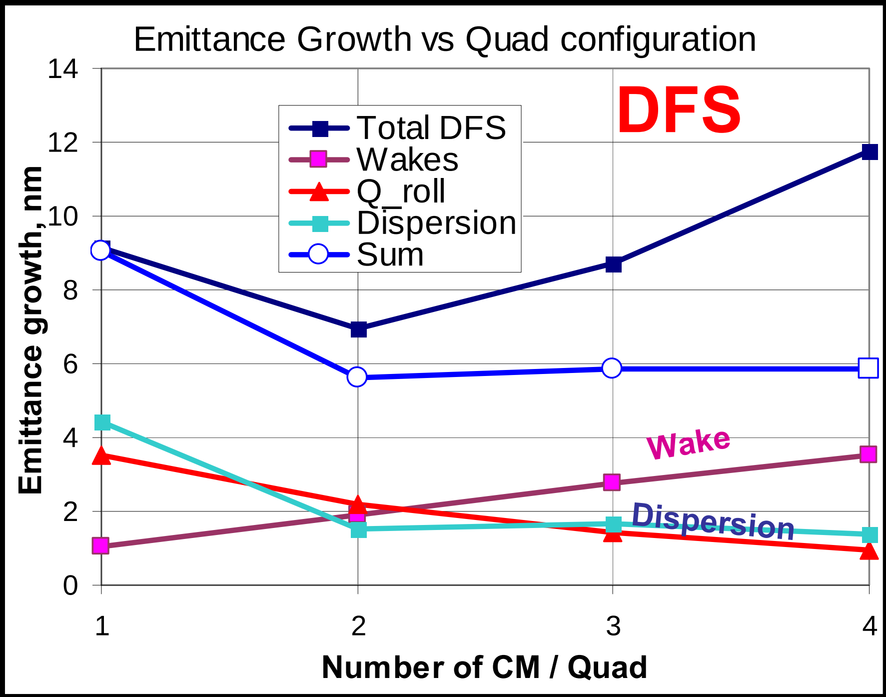






EMITTANCE DILUTION – SOURCES





DFS:

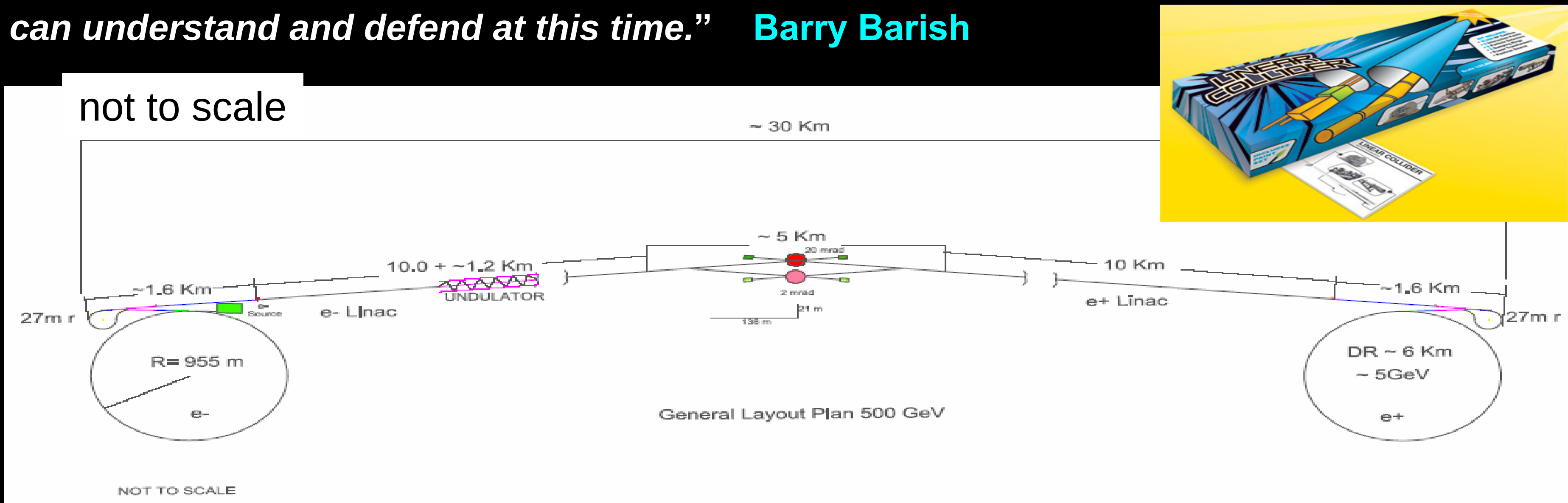
1Q/2CM is equilibrium optics with equal contribution from each source. Optics with larger quad spacing is wakefield dominated with the systematic wake-related contribution (Sum of all three contributions is smaller that the total calculated emittance growth).

Status after
Baseline Configuration Document (BCD)

Released at the Frascati GDE meeting in December, 2005

ILC MAIN LINAC - BCD

☛ ***"The baseline configuration document (BCD) [for ILC] is a snapshot of what we can understand and defend at this time."*** **Barry Barish**



➢ **TUNNEL - "Until on-going beam dynamics simulations show otherwise, the *linac will follow the curvature of the earth*, unless a site-specific reason (cost driven) dictates otherwise."**

➢ **CAVITY - "*31.5 MV/m gradient* and *Q of 1×10^{10}* would be achieved on average in a linac made with *eight-cavity cryomodules*."**

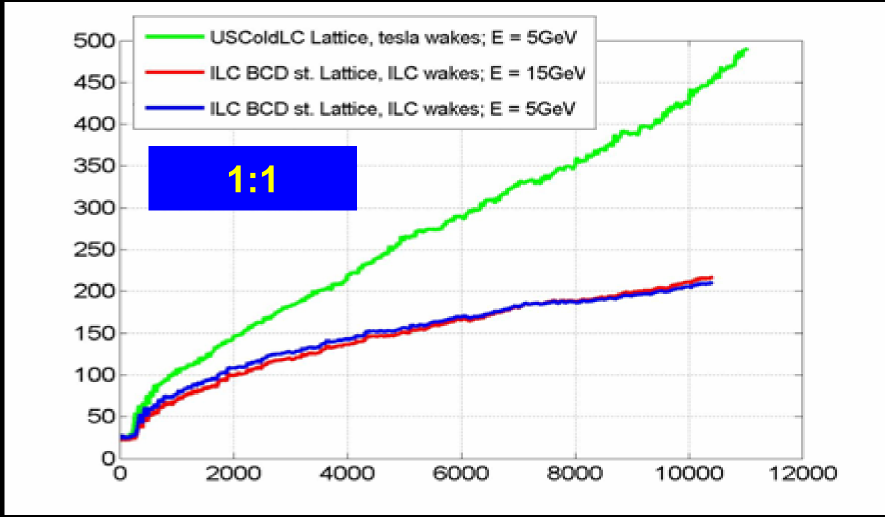
➢ **LATTICE – *"Every fourth CM* in the linac would include a cos(2*phi)-type *quadrupole* that also would contain horizontal and vertical corrector windings (this corresponds to a *constant beta lattice with one quadrupole every 32 cavities*). "**

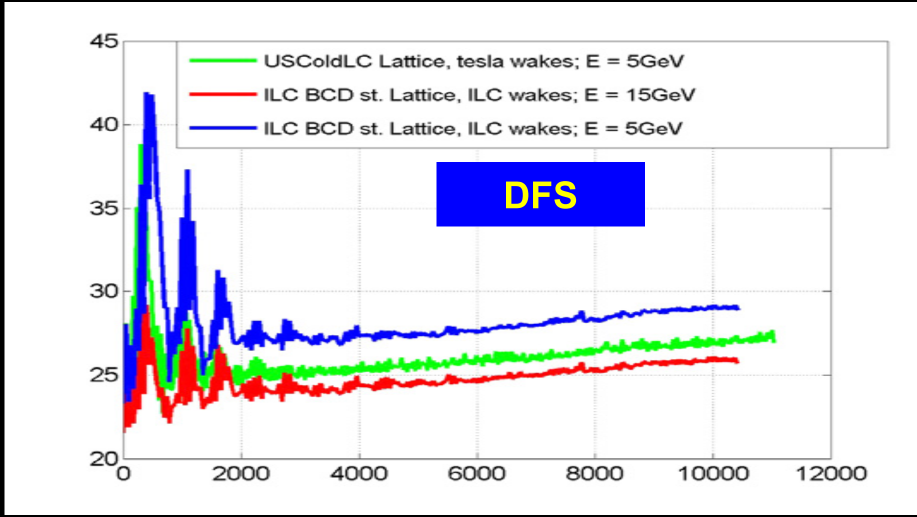
USColdLC vs. ILC BCD

- ✓ Comparison of the LASER STRAIGHT LINACs (ILC BCD vs. USColdLC)
- ✓ All nominal misalignments included; No Jitter, No dispersion bumps; 100 seeds

A.) US Cold LC Lattice (1Q/24 cavity), TESLA wakes, E = 5 GeV, Espread = 125 MeV (2.5%)
B.) ILC BCD Lattice (1Q/32 cavity), TESLA wakes, E = 5 GeV, Espread = 125 MeV (2.5%)
C.) ILC BCD Lattice (1Q/32 cavity), ILC wakes, E = 15 GeV, Espread = 150 MeV (1.0%)

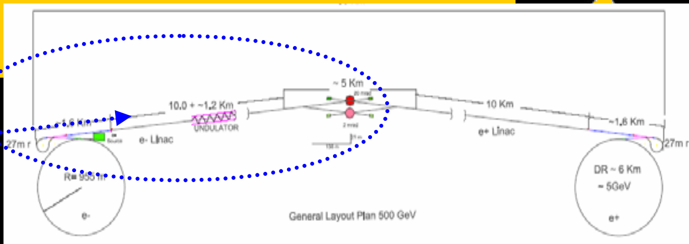
Mean projected Normalized Emittance (nm) vs. Linac length (m)





	Mean dilution (nm)		90% dilution (nm)	
	1:1	DFS	1:1	DFS
USCold LC	471 ± 38	6.9 ± 0.4	940	13.1
ILC BCD (5 GeV)	191 ± 16	8.9 ± 0.6	387	15.5
ILC BCD (15 GeV)	197 ± 17	5.7 ± 0.4	398	9.8

LIAR ADD-ONS



➢ Earth curvature effect in simulation : can be done

⇨ using vertical S-bend magnets (requires significant work in LIAR particularly since it is meant originally for the laser-straight linacs)

⇨ by actually placing the beamline elements on the earth curvature using offsets and pitch (some limitations as in LIAR Quads don't have the pitch) – Alexander Valishev + Nikolay Solyak

✓ using an arbitrary "dispersion-free" geometrical kick (GKICK) which places beamline elements on the earth curvature by changing the reference trajectory

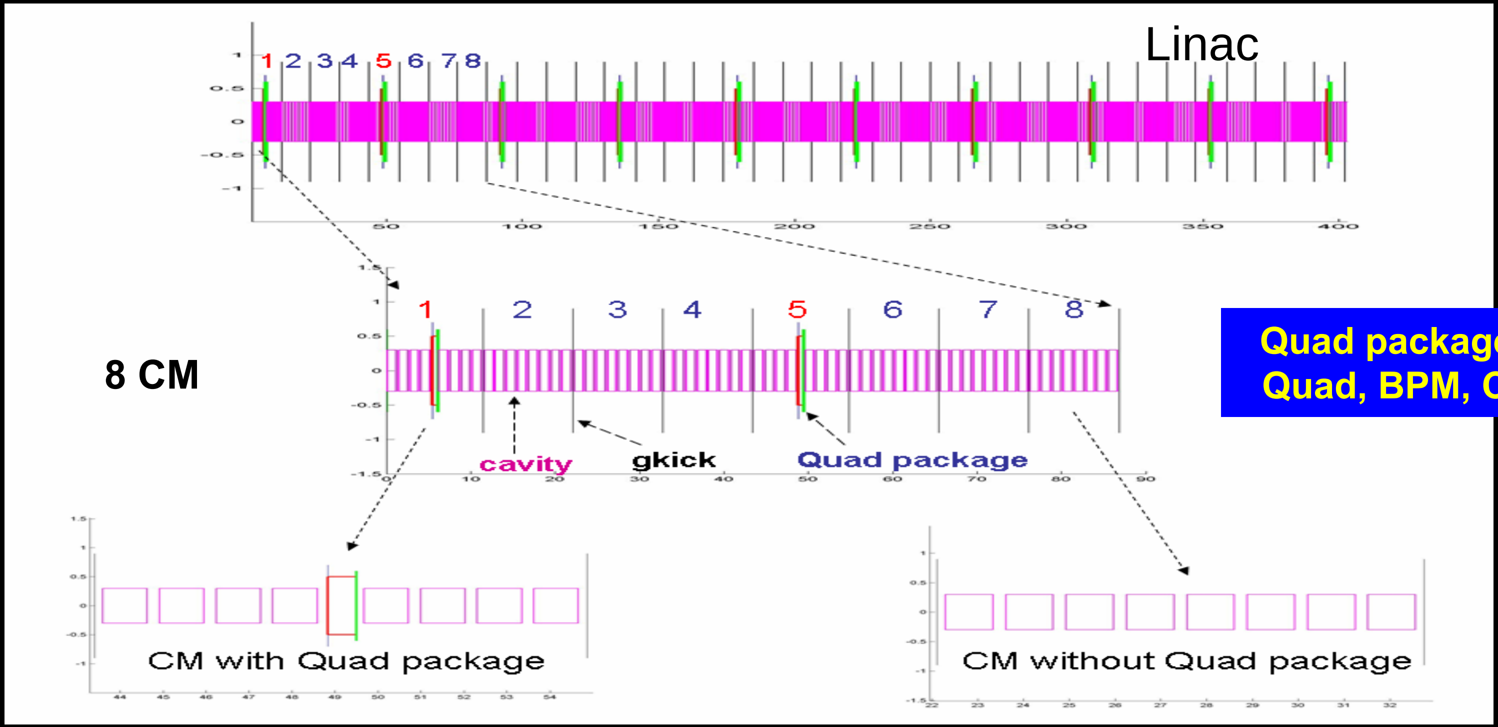
⇨ Didn't exist in LIAR. Francois Ostiguy has helped in adding this feature.

⇨ **issue about the geometrical transformation - further checks are being carried out**

➢ In LIAR, dispersion could not be used as initial condition and there was no provision for propagating it through the Linac

⇨ Francois has added this feature. The matched dispersion condition at the beginning of the linac can now be artificially introduced into the initial beam (w/o constructing any matching section)

ILC BCD CURVED LINAC - SIMULATION



Quad package = Quad, BPM, COR

- Length of CM w/o Quad = 10.651 m; Length of CM w/ Quad = 11.452 m
- To place the beamline elements on the earth curvature, each of the CM is given two half kicks in y-direction using GKICK (one at the beginning and other at the end)

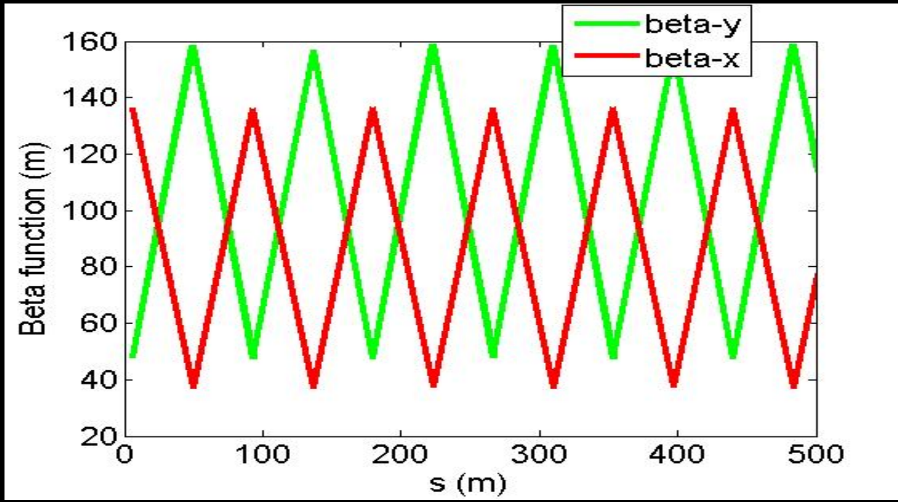
  ANGLE_CM = L_CM / R_Earth / 2 = 0.8360 μrad (or 0.8989 μrad)

- Since YCORs are with the Quads (which are 1 / 4CM), so an equivalent kick is given to beam to launch it into the reference orbit set by earth curvature

  - (2 * ANGLE_CM_Quad + 6 * ANGLE_CM_NoQuad) = - 6.8139 μrad

ILC MAIN LINAC - BCD

- ILC Main Linac Design
  - Linac Cryogenic system is divided into CM, with 8 RF cavities / CM
  - 1 Quad / 4CM : Superconducting Quads in every fourth CM,
  - FODO "constant beta" lattice, with phase advance of 75^0 / 60^0 in x/y plane
  - Each quad has a *BPM* and a *Vertical & Horizontal Corrector* magnet;



- Main Linac Parameters
  - ~11.0 km length
  - 9 Cell cavities at 1.3 GHz;
  - Loaded Gradient : 31.5 MV/m
  - Injection energy = 15.0 GeV
  - Initial Energy spread = 1.07 %(~150MeV)
  - Extracted beam energy = 251.8 GeV

Length (m) :	10417.20
N_quad :	240
N_cavity :	7680
N_bpms :	241
N_Xcor :	240
N_Ycor :	241
N_gkicks :	1920

- Beam Conditions
  - Bunch Charge: 2.0×10^{10} particles/bunch
  - Bunch length = 300 μm
  - Normalized injection emittance: $\gamma\varepsilon_Y$ = 20 nm-rad

GKICK checks

✓ GKICK provides the reference trajectory (to incorporate earth curvature effect) so that all the beamline elements get placed on that reference.

✓ YCOR launches the beam on to that reference trajectory

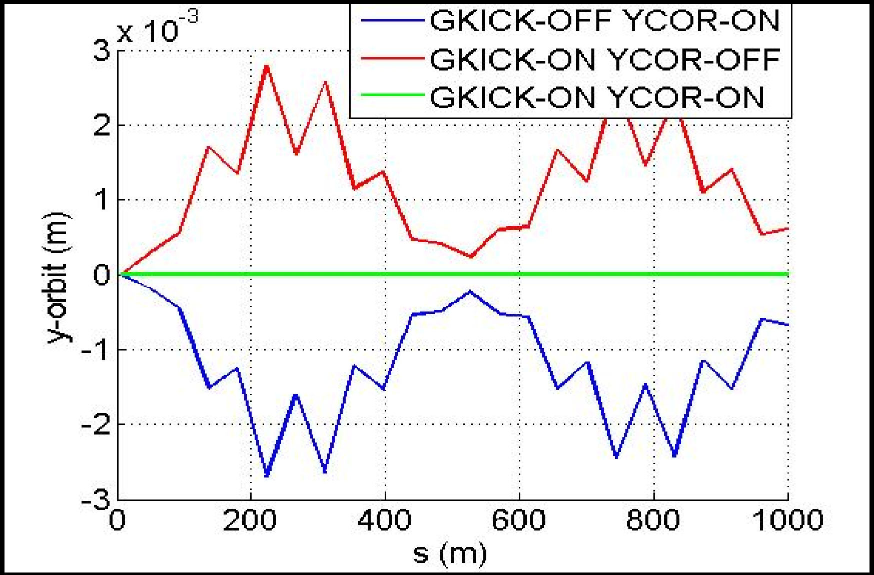
Three cases are simulated

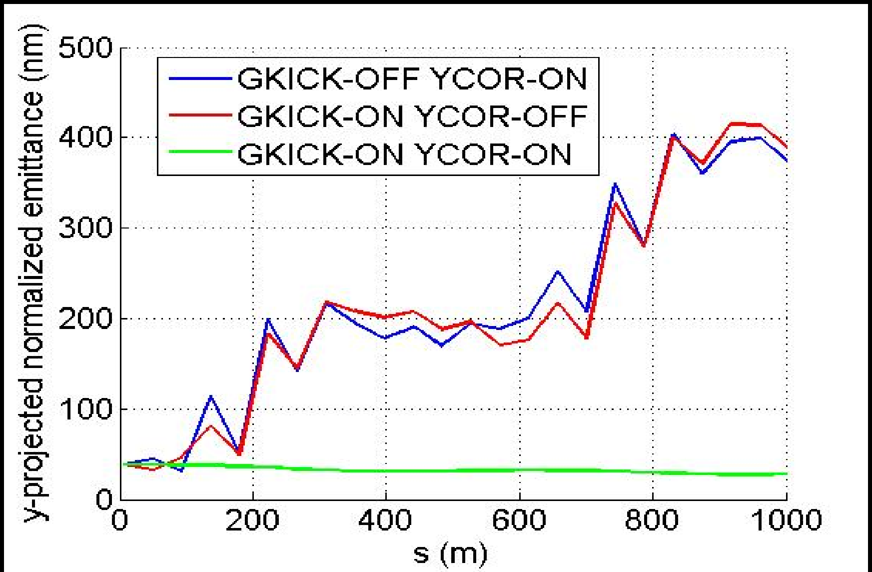
A.) GKICK - OFF , YCOR - ON => Terrible case ☹

B.) GKICK - ON , YCOR - OFF => Terrible case ☹

C.) GKICK - ON, YCOR - ON => Nominal case ☺

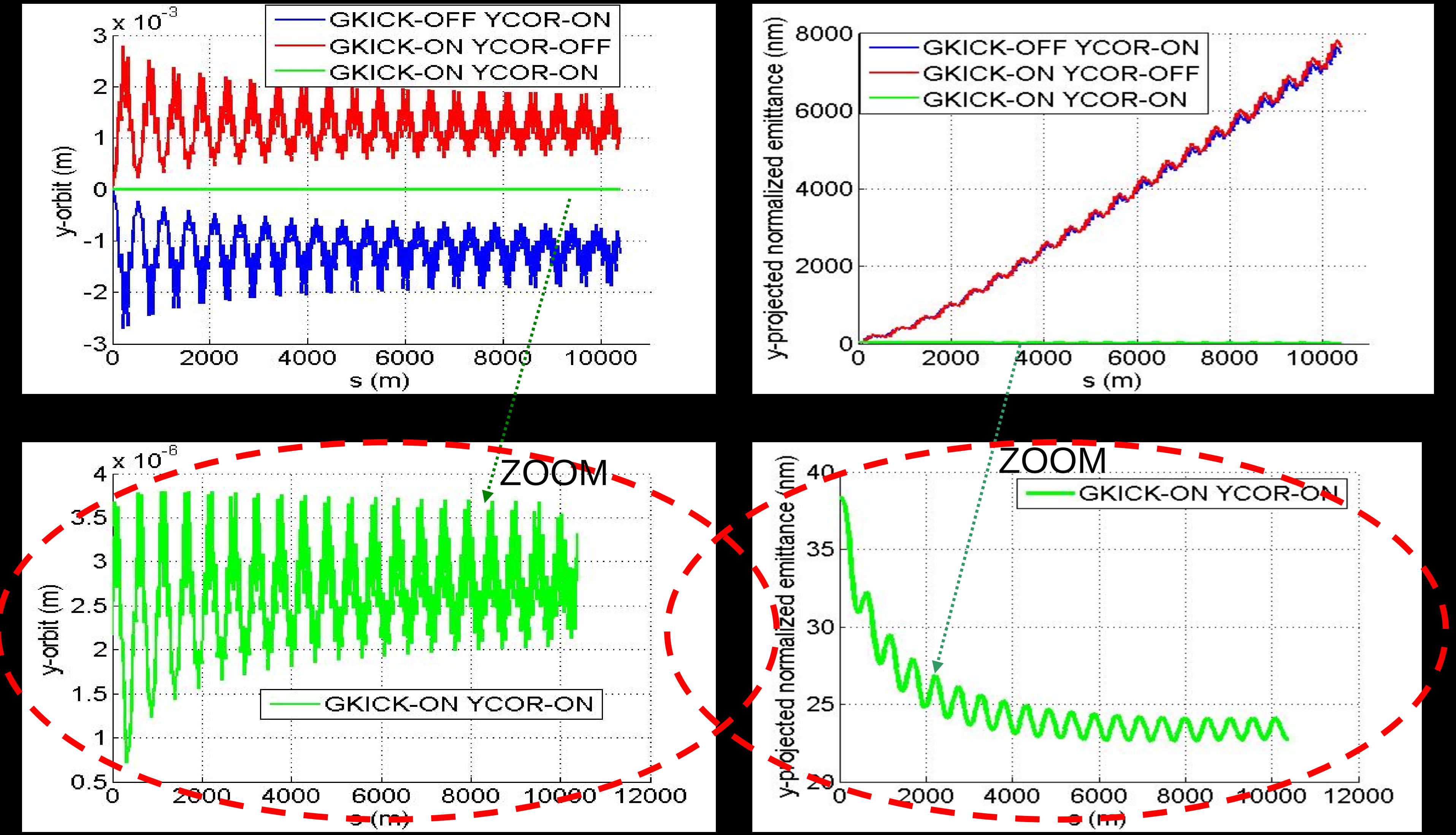
ILC BCD LATTICE
1st 1000 meters





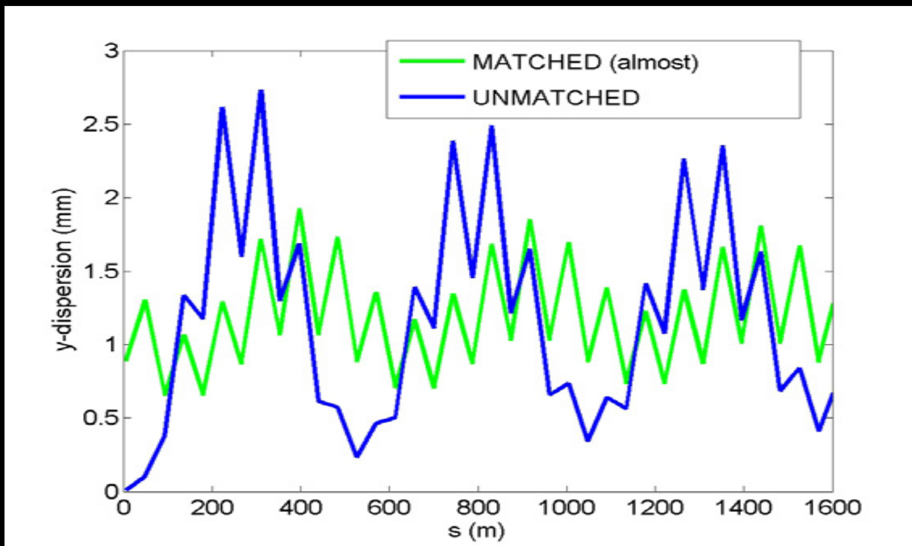
GKICK checks

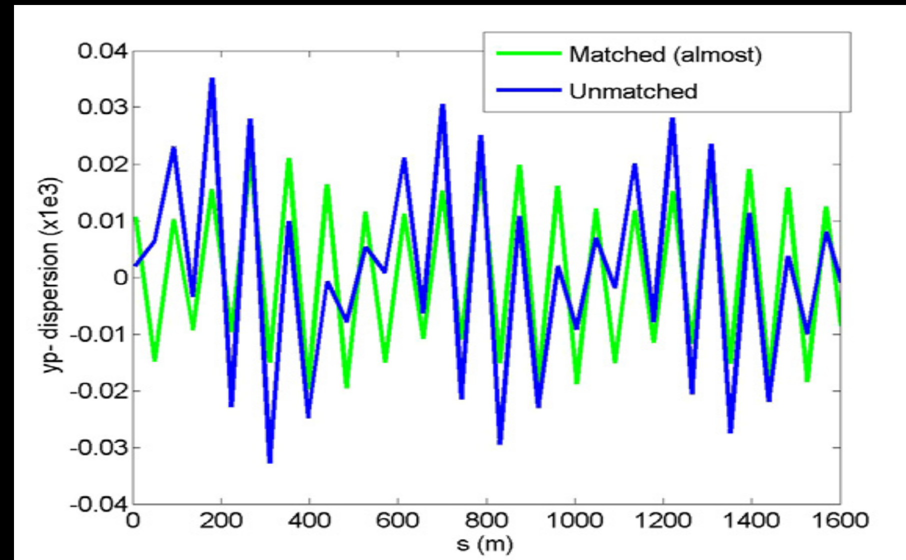
FULL ILC BCD LATTICE: Measurements at the YCOR locations (matched dispersion)

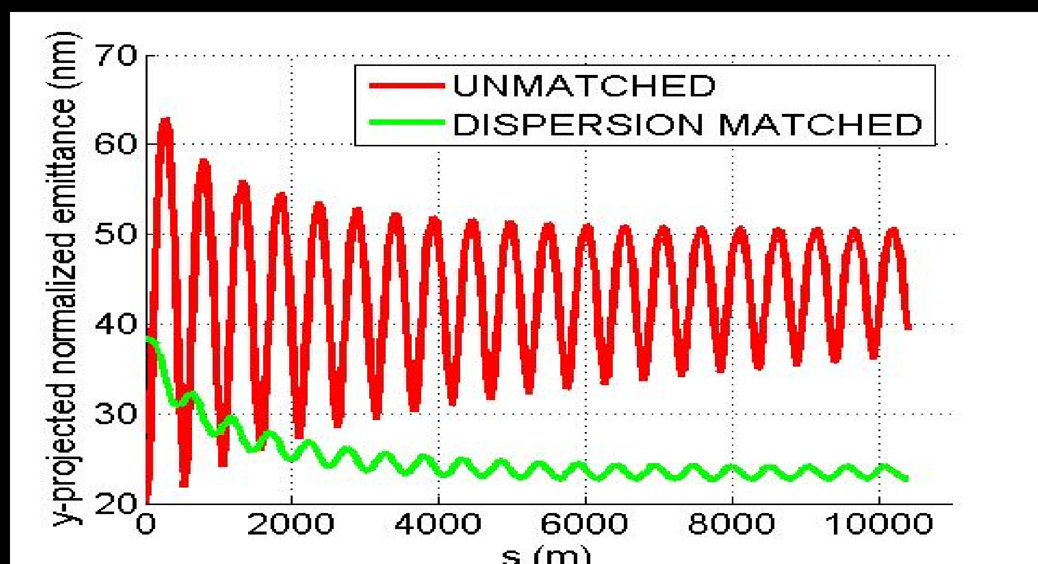


ILC BCD Main Linac: Matched Lattice

1st 1600 m of ILC BCD CURVED LATTICE: matched dispersion





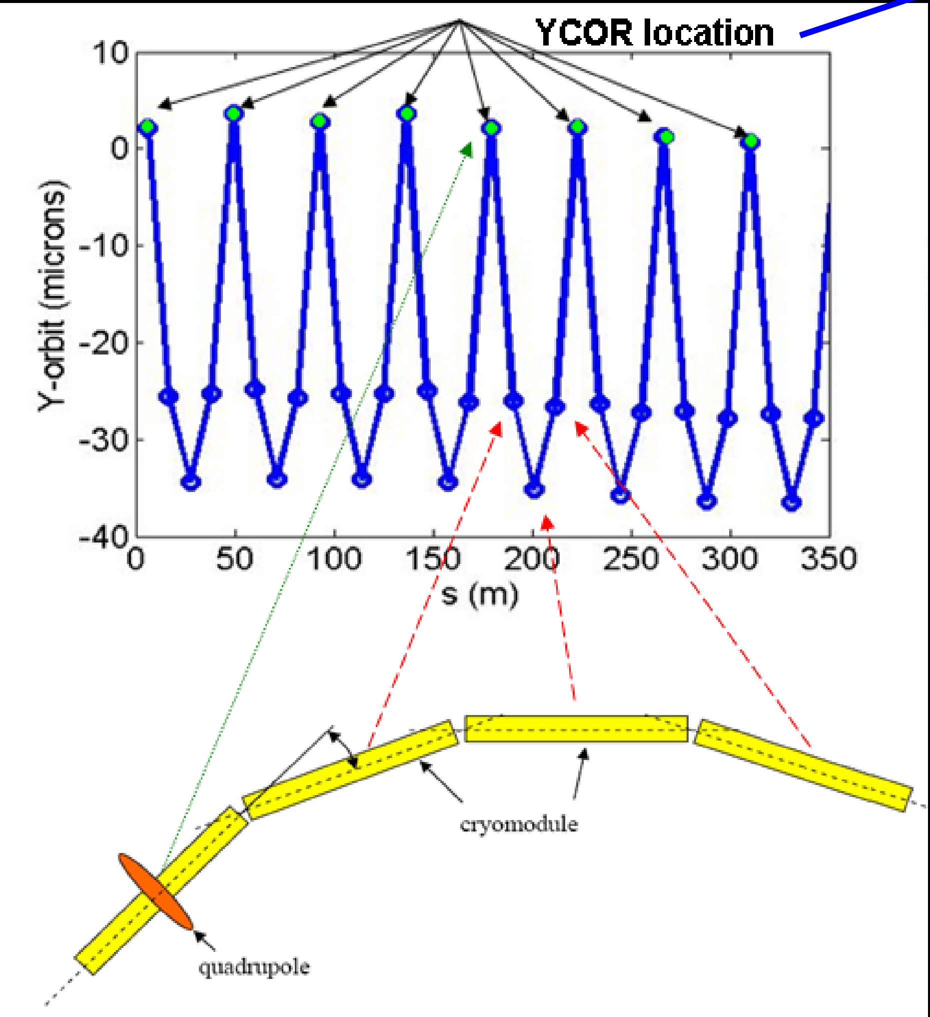


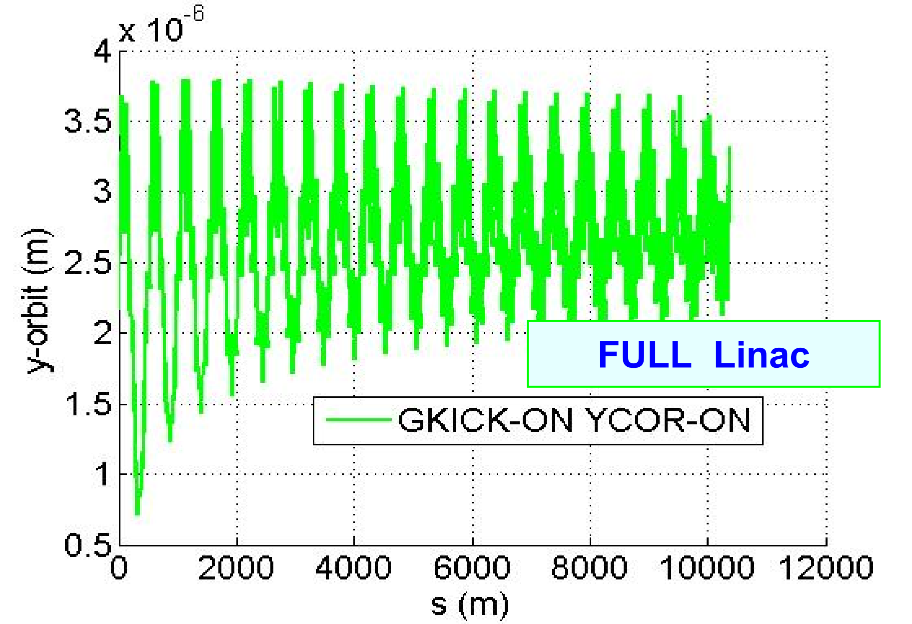
ILC BCD: Curved Linac

✓ **Matched initial beam conditions are used**

Y-orbit (BPM at the centre of each CM)

Y-orbit only at YCOR locations (4^{th} CM)





✓ **Systematic offset of (maximum) ~40 μm through the cavities**

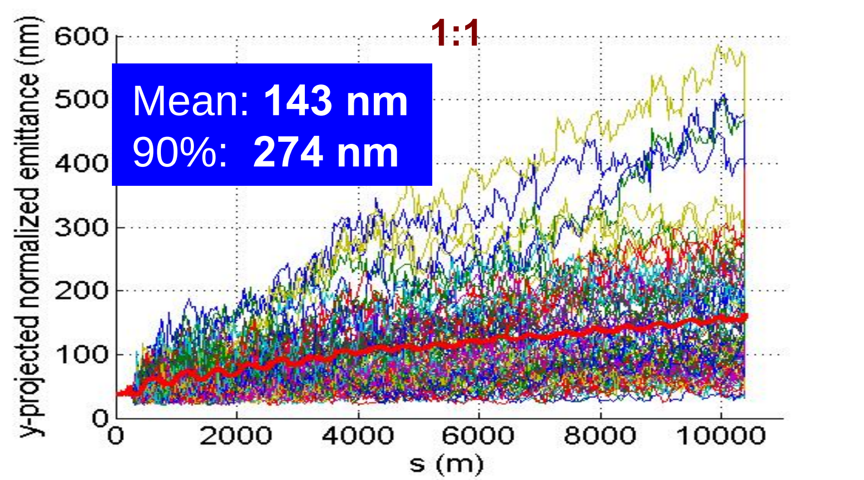
<

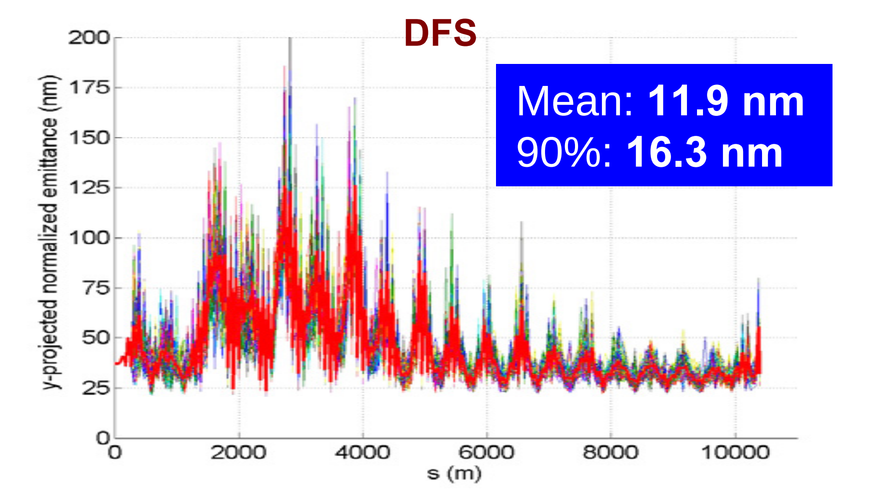
Expected 300 um RMS cavity and 200 um RMS CM alignments (Random) foreseen in ILC main Linac

ILC BCD: Curved vs. Straight Linac

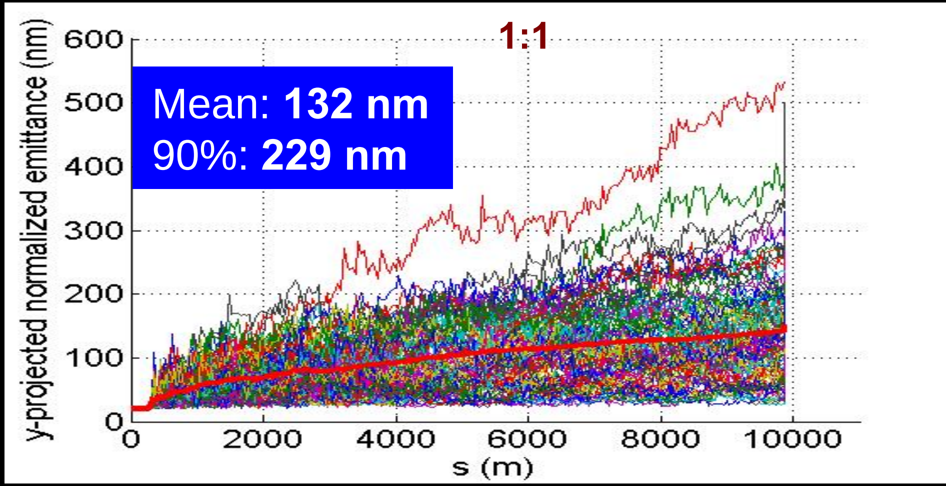
- ✓ Matched initial beam conditions are used ; 100 seeds; BPMs only at YCOR locations
- ✓ All nominal misalignments except that all errors in 1st 25 CMs are reset to 0; WAKES ON

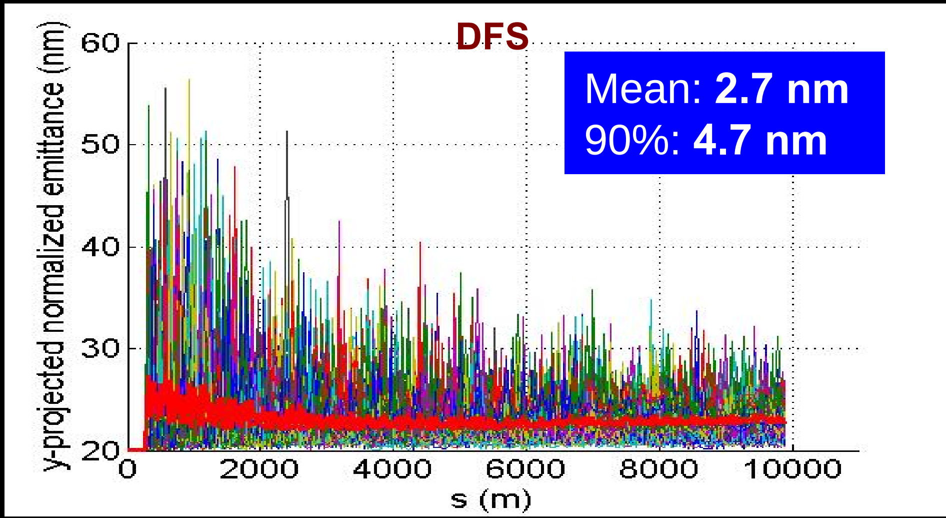
CURVED





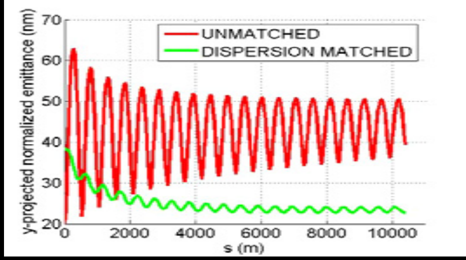
STRAIGHT



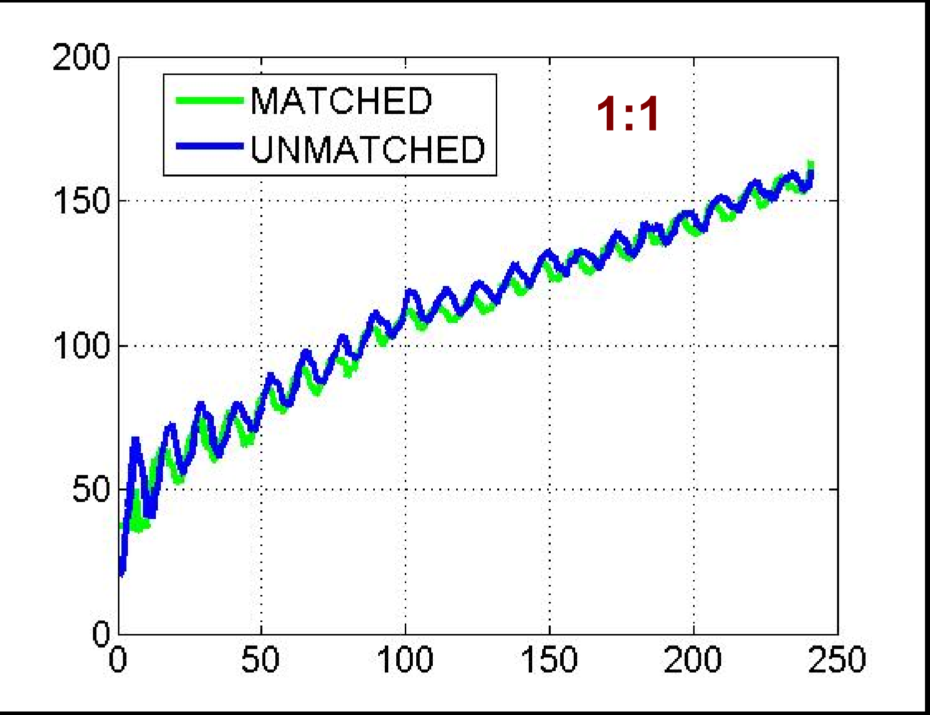


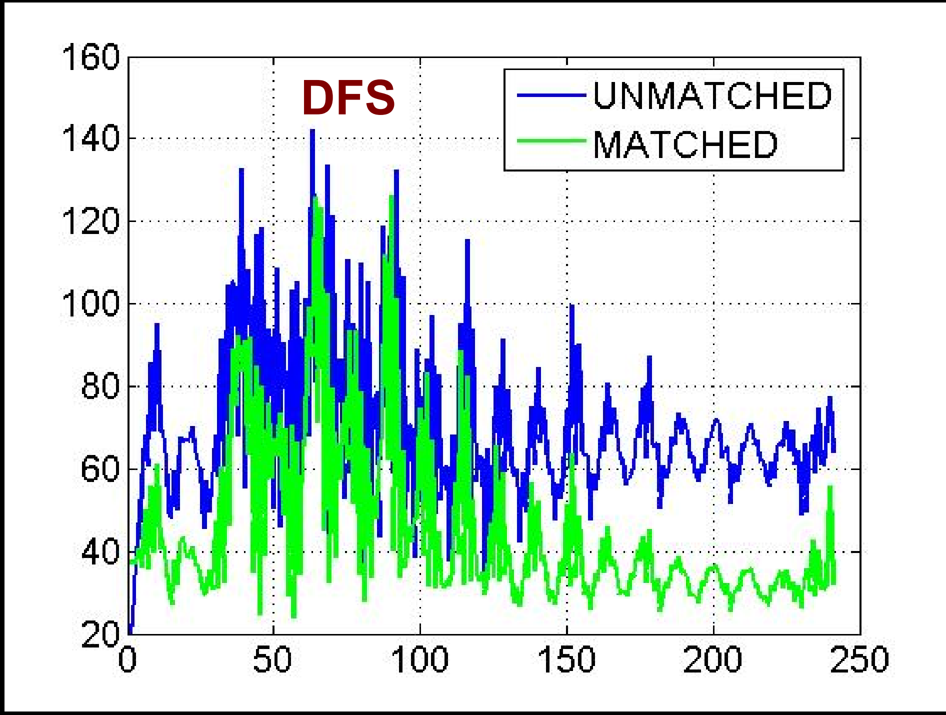
ILC BCD CURVED: Matched vs. Unmatched

- ✓ 100 seeds; BPMs only at YCOR locations; WAKES ON
- ✓ All nominal misalignments except that all errors in 1st 25 CMs are reset to zero



Mean projected Normalized Emittance (nm) vs. BPM index

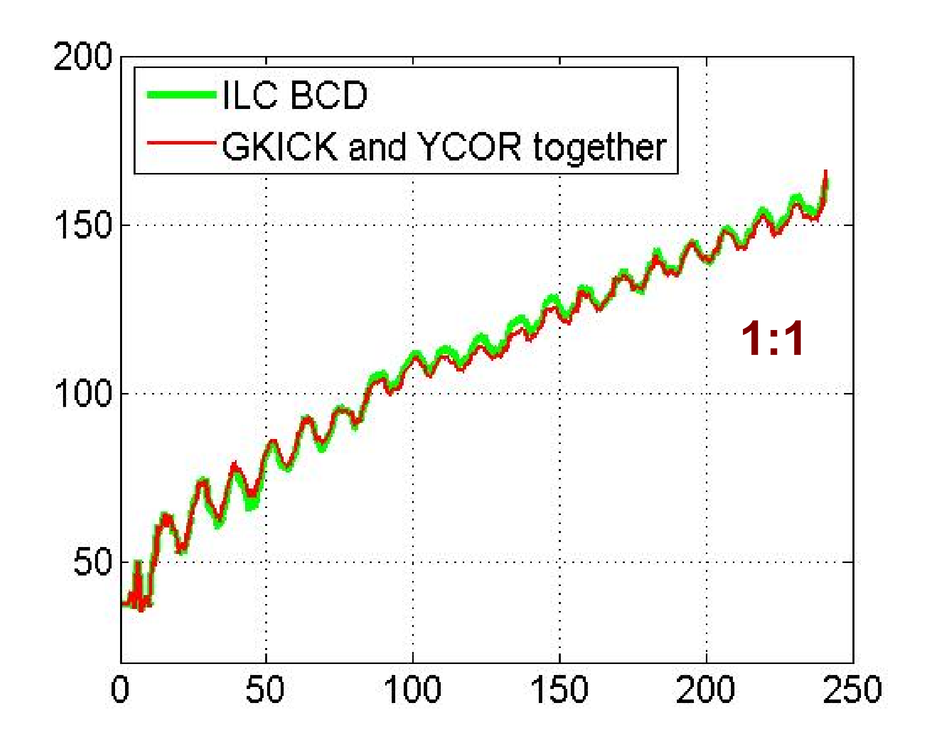


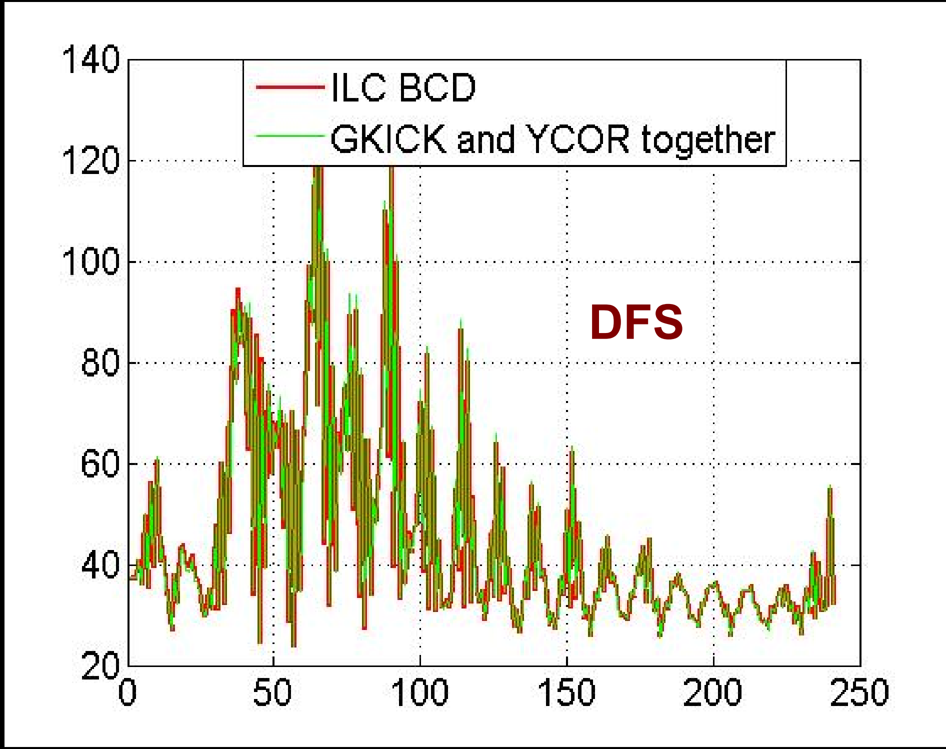


Two different CURVED geometries

- ✓ Compare ILC BCD curved linac with a design where GKICK and YCOR are placed together at the centre of every 4th CM
- ✓ Matched beam conditions; 100 seeds; BPMs only at YCOR locations; WAKES ON
- ✓ All nominal misalignments except that all errors in 1st 25 CMs are reset to zero

Mean projected Normalized Emittance (nm) vs. BPM index





BENCHMARKING / CROSS – CHECKING

SINGLE BUNCH EMITTANCE DILUTION WITH STATIC MISALIGNMENTS

BENCHMARKING

➢ In the various results presented during SNOWMASS and in the recent LET workshop at CERN, differences among the various Main Linac simulation codes were found.

- Differences in the emittance dilution predictions and sensitivity of the beam based alignments.

➢ Thus, it is generally felt by LET community to understand these subtle differences carefully and hence various analyzers have agreed to cross-check results and so far two exercises were attempted

- Codes compared

BMAD (TAO) -- Jeff Smith (Cornell)

PLACET -- Daniel Schulte (CERN)

MERLIN -- Nick Walker (DESY) & Paul Lebrun (Fermilab) separately

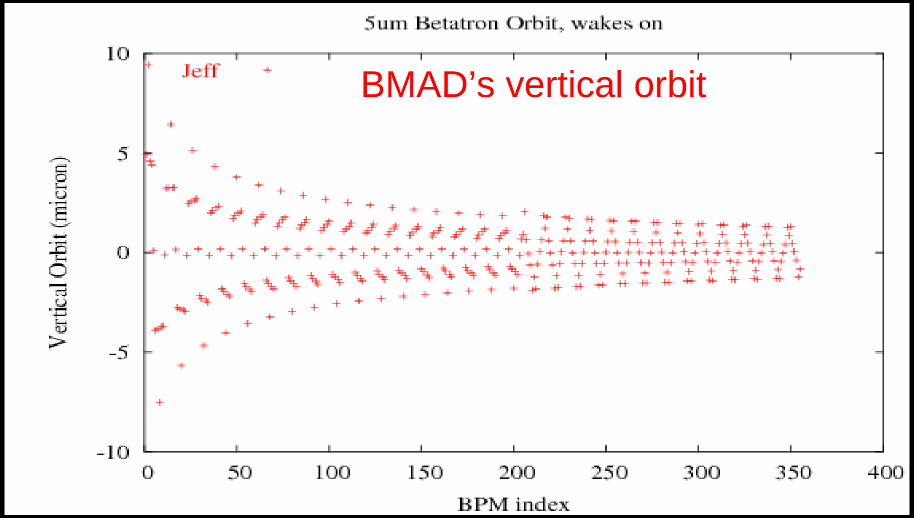
SLEPT -- Kiyoshi Kubo (KEK)

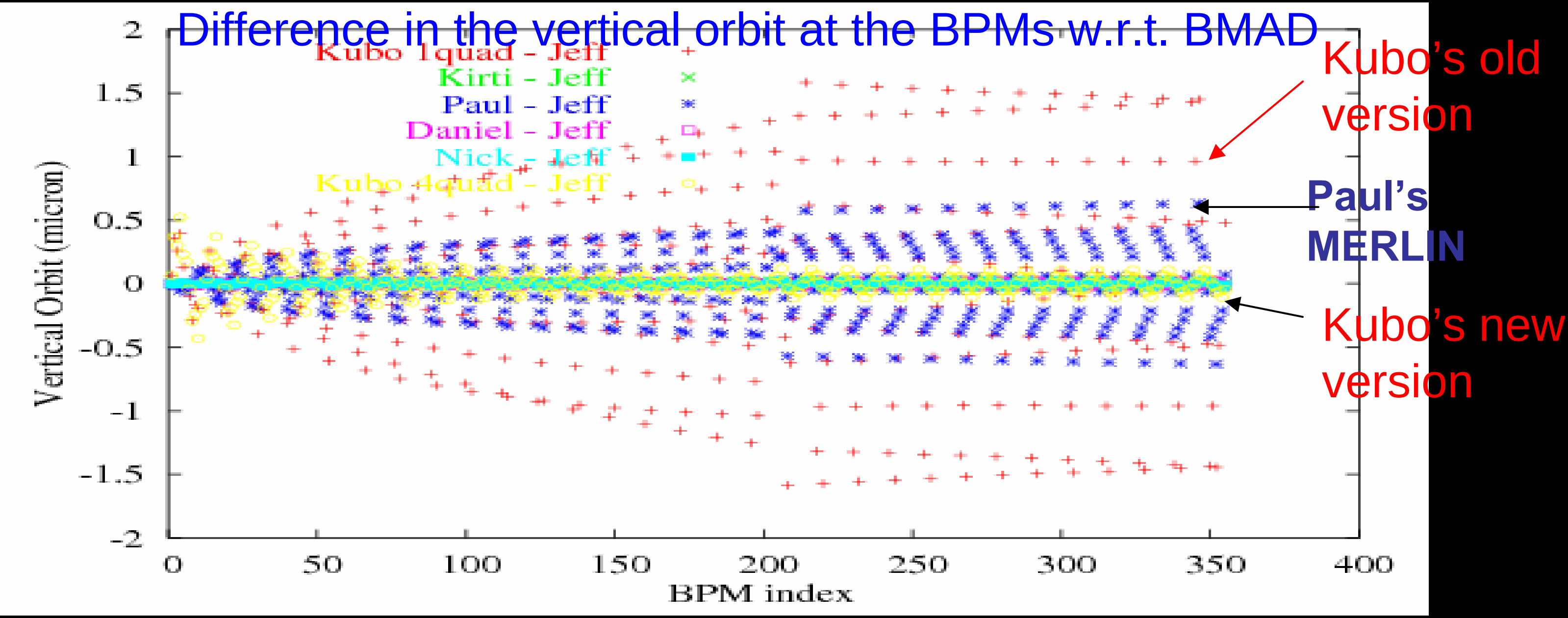
MATLIAR -- Peter Tenenbaum (SLAC) and Kirti Ranjan (Fermilab)

BENCHMARKING Exercise # 1

- In perfectly aligned LINAC (TESLA lattice), launch the beam with the initial y-offset of 5 microns (including TESLA wakes)

- Half Linac is low energy section and half if the high energy section.

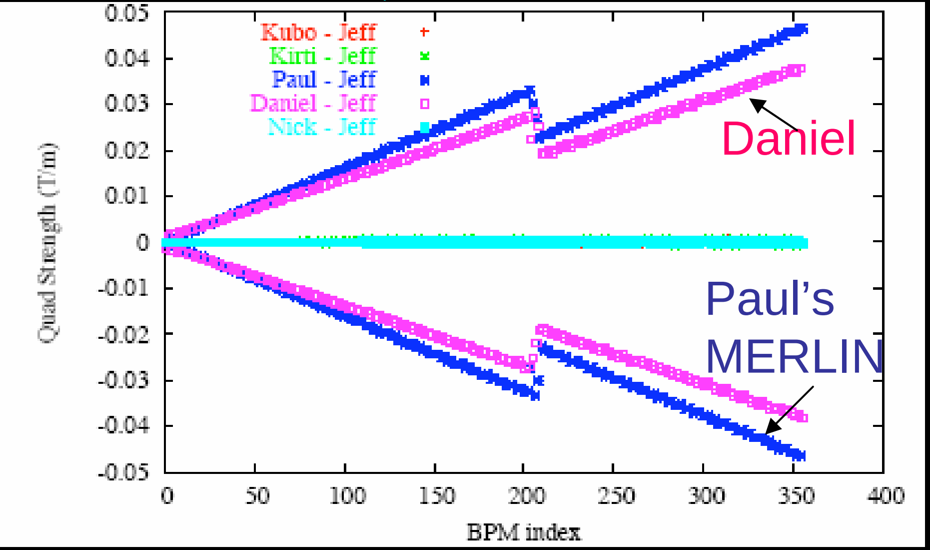




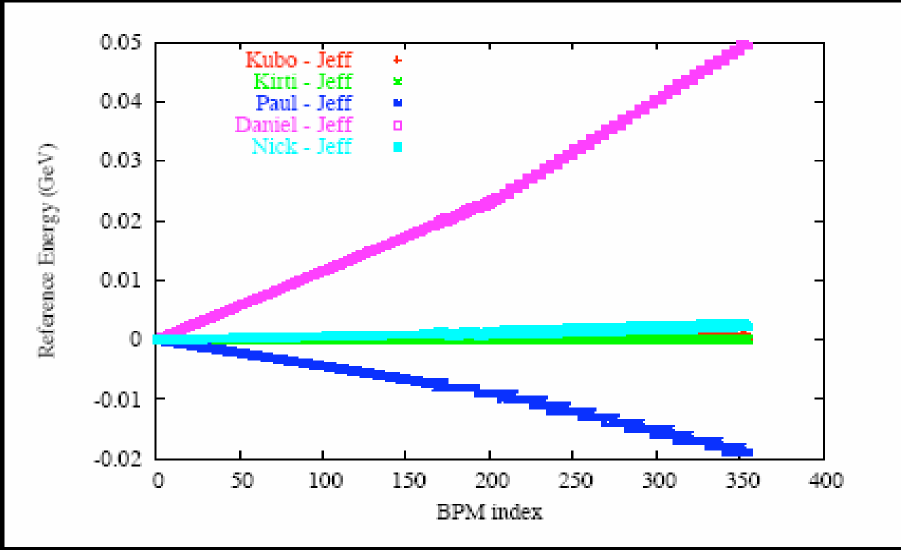
- Paul's new results are consistent with the Nick's MERLIN results

BENCHMARKING Exercise # 1

Diff. in QUAD STRENGTH



Diff. in REFERENCE ENERGY

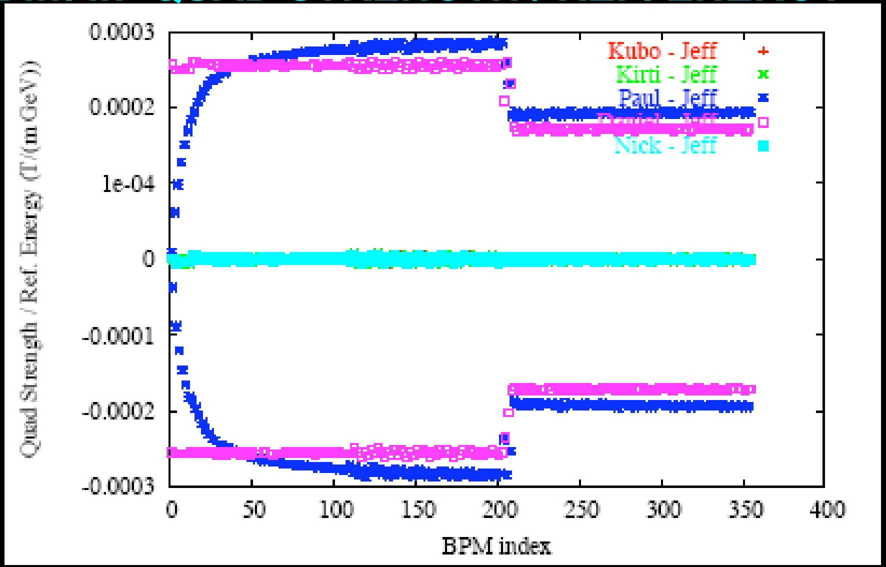


- **Ref. energy and Quad. Strengths of PLACET is quite different**
  - **PLACET - because of the diff. in the interpretation of ELOSS**

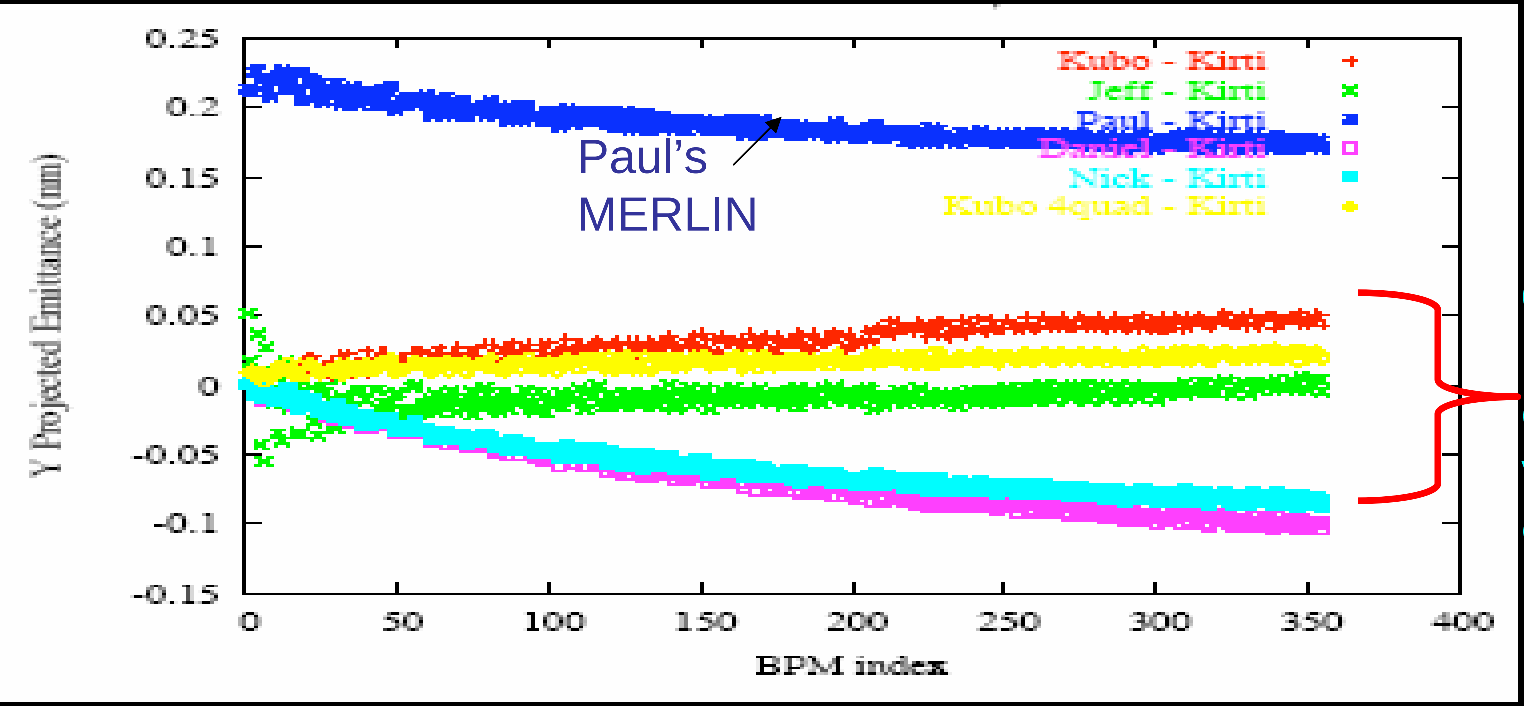
- **Differences in Quad strength/ Ref. energy is found in PLACET, beam trajectory doesn't look significantly different.**

- Paul's new results are consistent with the Nick's MERLIN results

Diff. in QUAD STRENGTH / REF. ENERGY

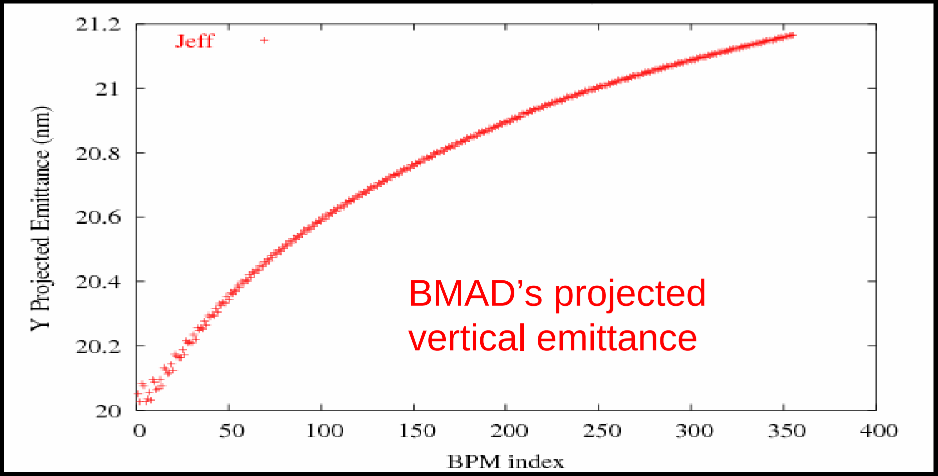


Diff. in PROJECTED VERTICAL EMITTANCE w.r.t. MATLIAR



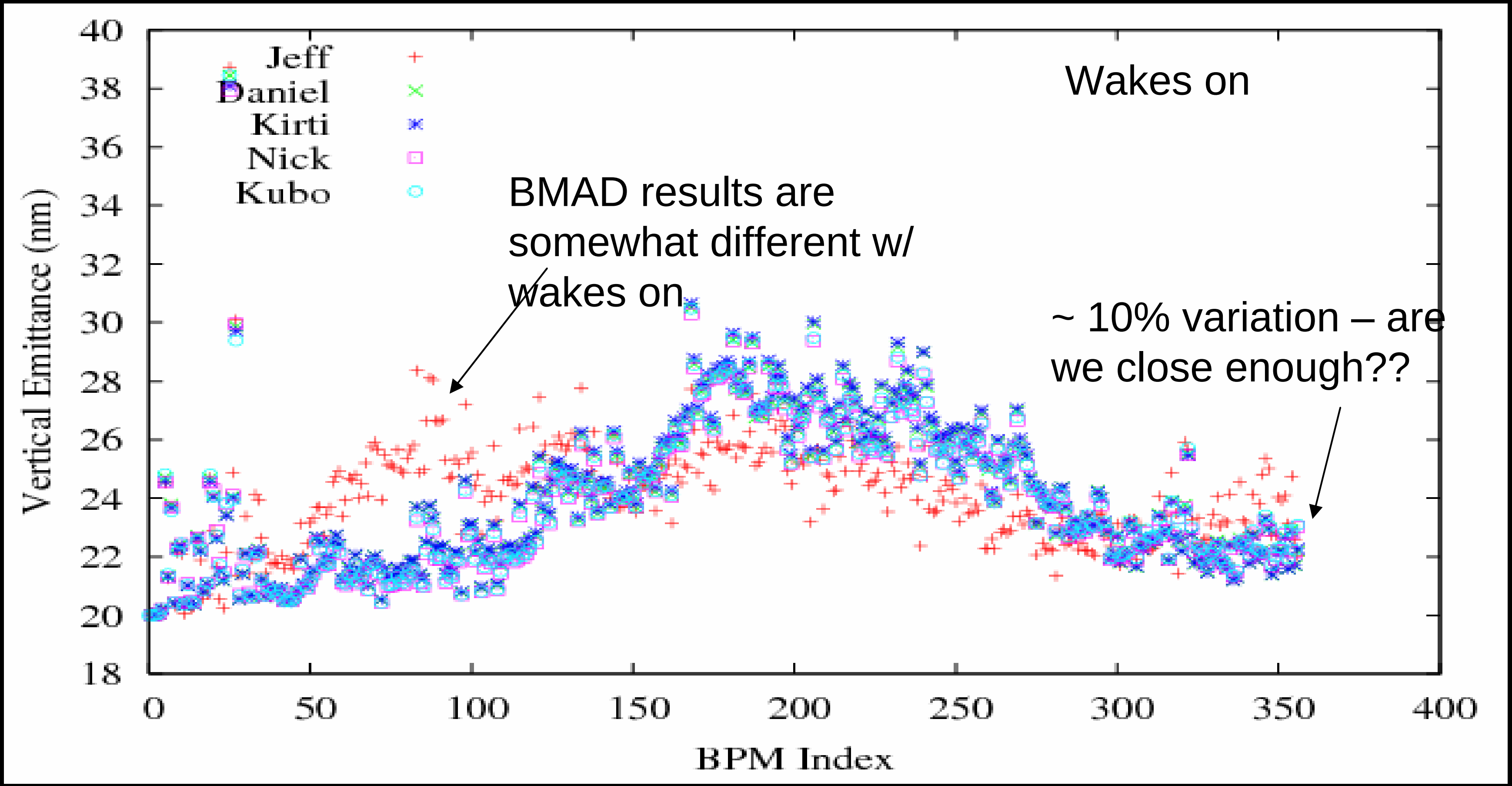
0.1 nm diff. for 1.2 nm emittance growth : 10% variation – are we close enough??

- Paul's new results are consistent with Nick's MERLIN results

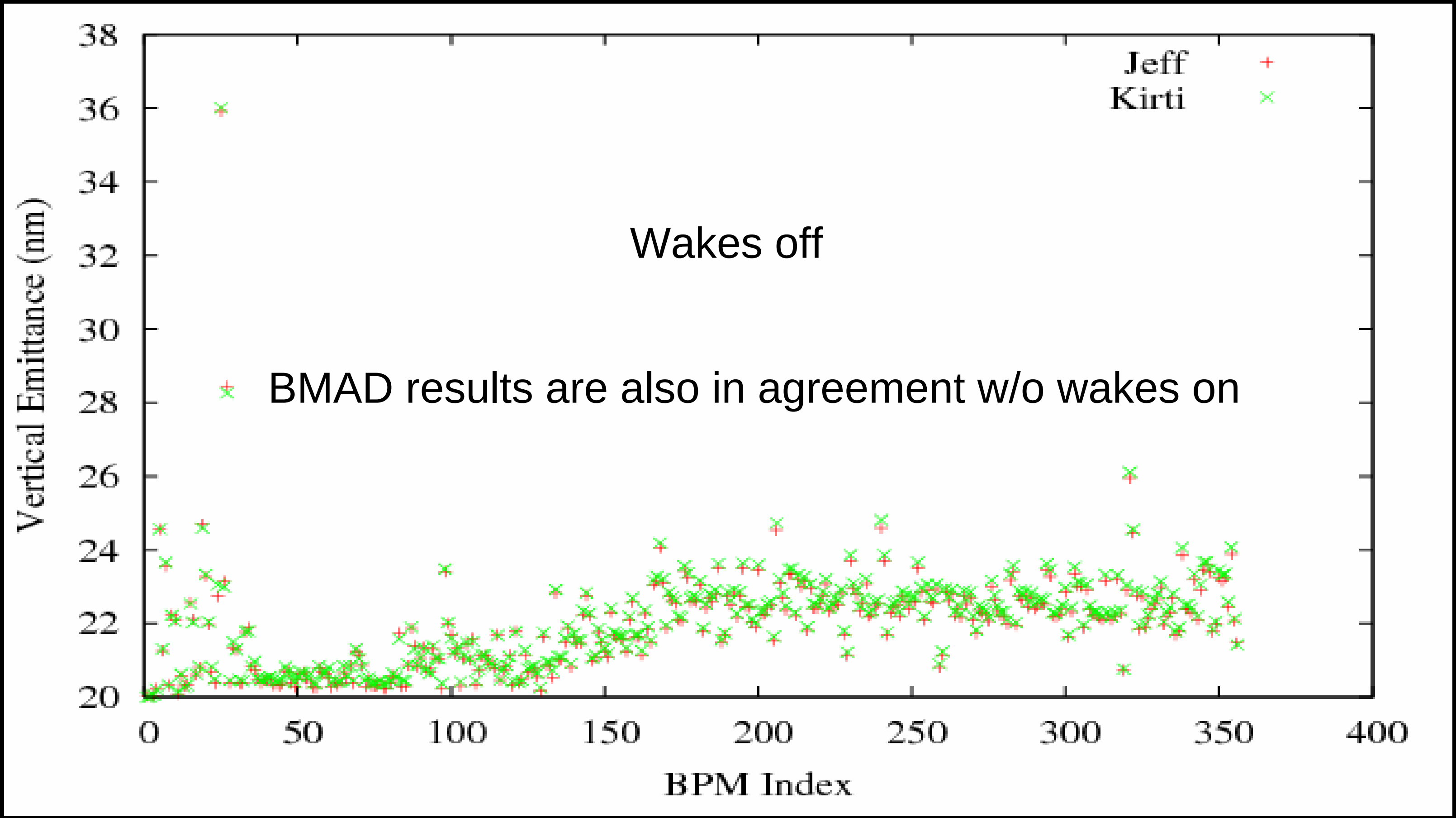


BENCHMARKING Exercise # 2

- PT (SLAC) generated the Misalignments file (for Quads, BPMs and cavities) using MATLIAR
- Then he generated the vertical corrector's setting for the DFS
- Exercise: Include the misalignments and the vertical corrector's setting and plot the emittance dilution



BENCHMARKING Exercise # 2



How close do we want to be? - I would say that If we can show agreement among various codes at the 10% level w/ all the input ingredients then it would be REASONABLE agreement

Summary

➢ We have studied the single bunch emittance dilution for USColdLC Main Linac, compared 1:1 and DFS for static misalignments, and also studied the sensitivity of these algorithms

➢ Studied various lattice configurations for the design of ILC BCD

➢ LIAR has been modified to study the curved Linac

☺ Preliminary results of the ILC BCD curved Linac show that the there is no significant impact on the achievable emittance from the linac which follows the Earth's geometry as compared to the straight linac.

➢ Different groups have been able to find some small bugs / differences in their code while doing benchmarking tests.

➢ Most of the codes show agreement w/ each other now at the 10% level.

➢ Recently Leo showed the verification of exercise # 1 using CHEF…development is going on…seems like a promising simulation package !

Plan

- Close look at the ILC BCD curved linac and perform various sensitivity studies and understand the tolerances

- Understanding of the outstanding issues of the DFS (for ex. Improved Launch steering and wake related systematic effects)

- Add Beam Jitter, Quad Jitter, Ground motion, Dispersion bumps

- Bad seeds studies

SIMULATION: LIAR

- Beam with a total charge Q is described as a train of N_b bunches $Q = \sum_{j=1}^{N_b} Q_j$
- Each bunch is longitudinally divided into Ns slices that are located at different positions in z.

$$Q_j = \sum_{i=1}^{N_s} \Gamma_z(\sigma_z, z_i) \cdot Q_i$$

- Each slice is divided into N_m mono-energetic beam ellipses $Q_i = \sum_{i=1}^{N_m} \Gamma_E(\sigma_E, E_m) \cdot Q_m$
- Vector X describes the centroid motion of thin longitudinal slice

$$X = \begin{pmatrix} x \\ x' \\ y \\ y' \\ z \\ E \end{pmatrix}$$

- With each slice, a beam matrix is also associated $\sigma = \begin{bmatrix} \sigma_{xx} & \sigma_{xx'} \\ \sigma_{xx'} & \sigma_{x'x'} \end{bmatrix} = \epsilon \begin{bmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{bmatrix}$
- Both the centroids X and the beam ellipses are tracked through the lattice

$$X_1 = \mathbf{R}\, X_0$$

$$\sigma_1 = \mathbf{R}\, \sigma_0\, \mathbf{R}^T$$

- Beam emittance w.r.t. beam centroid is defined as

$$\epsilon = \left[\sigma_{xx}\sigma_{x'x'} - \sigma_{xx'}^2\right]^{\frac{1}{2}}$$

where $\sigma_{xx} \quad = \quad \frac{1}{Q} \sum_{i=N_0}^{N} Q_i \left[(x_i - \overline{x})^2 + \sigma_{xx,i}\right]$

and so on

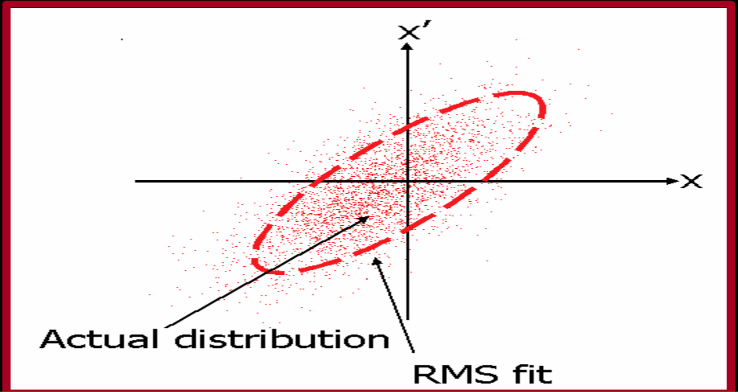
ILC BCD – Baseline Parameters

		min		nominal		max	
Bunch charge	N	1	-	2	-	2	$\times 10^{10}$
Number of bunches	n_b	1330	-	2820	-	5640	
Linac bunch interval	t_b	154	-	308	-	461	ns
Bunch length	σ_z	150	-	300	-	500	μm
Vert.emit.	$\gamma\epsilon_y^*$	0.03	-	0.04	-	0.08	mm·mrad
IP beta (500GeV)	β_x^*	10	-	21	-	21	mm
	β_y^*	0.2	-	0.4	-	0.4	mm
IP beta (1TeV)	β_x^*	10	-	30	-	30	mm
	β_y^*	0.2	-	0.3	-	0.6	mm

Baseline Parameters

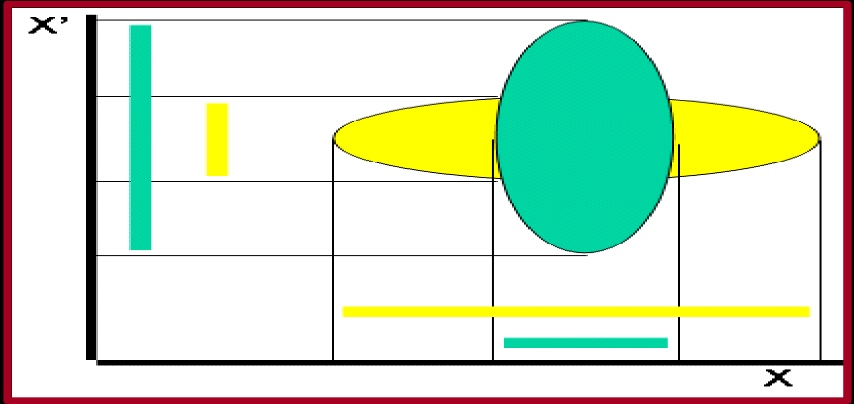
Emittance Dilution

- Property of the beam
- ~ Beam size * Divergence
- Phase space area occupied by the beam
- Normalised emittance is invariant in Conservative system

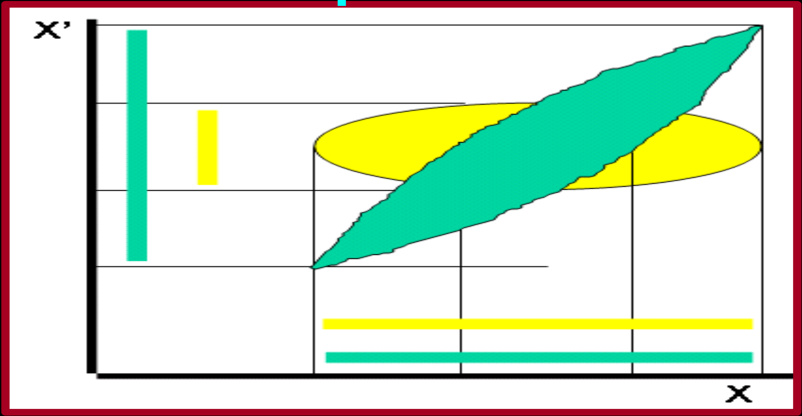


Beam particles distributed in Phase space

Uncoupled beam



Coupled beam



EMITTANCE DILUTION – In the presence of beam coupling, the product of the projections of the phase space area on the X and X' axes is a NOT a constant